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STANDARD ELECTRONIC MODULES EXPLORATORY DEVELOPMENT MODULE PACK--ETC(U)

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STANDARD ELECTRONIC MODULES

EXPLORATORY DEVELOPMENT MODULE PACKAGING STUDIES BY NAVAL WEAPON SUPPORT CENTER, CRANE AND NAVAL AVIONICS FACILITY, INDIANAPOLIS

FY 1976 SUMMARY REPORT

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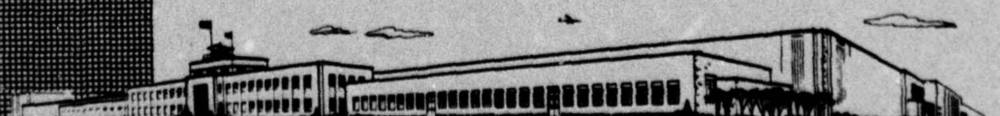

NAVAL AVIONICS FACILITY

INDIANAPOLIS, INDIANA 46218

NOTICE

FOREWORD

This report was prepared in response to the Standard Electronic Modules (SEM) Exploratory Development tasking from the Naval Electronics Laboratory Center, San Diego in accordance with the task statement attached to Work Request N0095376WR00134. The task accomplishments reported herein were a joint effort between the Naval Avionics Facility, Indianapolis (NAFI) and the Naval Weapons Support Center, Crane (NWSC).

The writer wishes to acknowledge the contributions of Jim Wolford, Ron Lannan, and Dave Reece of NWSC, Crane and Don Grayson, Bob Rodgers, and Ron Huss of NAFI in formulation of this report.

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ABSTRACT

This report summarizes the SEM Exploratory Development module packaging studies accomplished jointly by NAFI and NWSC, Crane during FY 1976. The primary outputs of these studies are the criteria and background data to be used in the definition of a SEM conceptual module, or family of modules, compatible with higher level electronic functions.

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I. CONCLUSIONS

A. The improved Standard Electronic Modules (SEM) module family is considered to be the optimum selection for a new module family based on the function data base analysis, trade-off criteria analysis, cost bounds analysis, and the desirability of retaining packaging compatibility with existing SEM. The improved SEM module family is a natural evolution of present SEM, and should be implemented into the SEM Program regardless of any additional new module family selection. Conclusions relative to the other four conceptual modules identified during the module studies are as follows:

1. Conceptual Module 1: Provides a nearly ideal fit with the function background task conclusions, but represents no increase in pins and only a marginal increase in power dissipation and active circuit board area over the improved SEM family.

2. Conceptual Module 2: The aspect ratio (height/span) results in potential mechanical integrity and thermal efficiency shortcomings.

3. Conceptual Module 3: The current unavailability of a reliable, producible zero insertion force connector and a DIP-compatible module configuration indicates that this module is not ready for near term standardization.

4. Conceptual Module 5: Problems in the areas of thermal efficiency, maintainability, and testability indicate that this module is not ready for near term standardization.

B. ARINC Specification 404A for ATR cases does not pose any significant engineering obstacles for housing standard modules; however, some modification to the ARINC case connector, mounting, and cooling interfaces will be required to achieve compatibility with the more severe military environmental requirements.

C. The functional background task indicates that a module with approximately 14 square inches of active circuit board area and 100 input/output (I/O) pins will satisfy 95 percent of known standard functions using DIPs. It is projected that only 20 to 40 functions having potential intersystem commonality can be identified which cannot be implemented on an improved SEM 2A module using DIPs.

D. The identification and development of a high density, light weight avionics module should be continued. As an alternative, hybrids should be considered as a valid means of size and weight reduction with potentially greater impact than high density packaging of conventional components. It must be recognized that adoption of a high density, larger module will result in establishment of a standardized mechanical package with a minimum of functions having potential intersystem commonality.

E. Other observations derived from the module studies include the following:

1. To achieve any significant benefits from SEM, standardization must be achieved at the functional level. Insignificant life cycle cost benefits will result if merely the mechanical and physical aspects of the modules are standardized. (See Reference A.)

2. Cost bounds for a standard module program point to the present SEM size as near the size above which life cycle cost begins to significantly increase with increasing module size.

3. The investigation of the module "use environment" indicates that a common environmental specification applicable to the majority of military applications can be achieved without excessive cost penalties.

4. The blade and tuning fork connector is generally accepted by industry as superior to others available.

5. It is projected that DIPs will be more widely used than flatpacks in the near term. The advent of larger LSI chips requiring additional I/O connections will hasten the use of other micro-circuit packages such as the leadless carrier.

II. RECOMMENDATIONS

A. Pursue the development of an improved SEM family on an expedited basis to implement into the SEM Program as quickly as possible.

B. Coordinate with NADC, Warminster; NWC, China Lake; and the Air Force to establish a conceptual module(s) consistent with the high density requirements of avionic hardware.

C. Adopt the ARINC ATR enclosure concept for airborne electronics based on satisfactory resolution of case connector, mounting, and cooling interfaces compatible with military environmental requirements.

D. Continue efforts to develop an optimum thermal interface for any new module(s) selected for the SEM family. The improved SEM family requires an improved conduction thermal interface.

E. Coordinate the recommendations of the Navy SEM R&D Program with the recommendations of the Air Force R&D Program and the Defense Material Specifications and Standards Board (DMSSB) Standard Modules Subpanel to arrive at a unified position.

F. Continue development of module support hardware such as lightweight card cages, interconnection techniques, etc.

G. Review proposed SEM modules with industry to obtain their recommendations.

III. INTRODUCTION

During FY 1976 a Standard Electronic Modules (SEM) Exploratory Development (6.2) Program was established with the Naval Electronics Laboratory Center (NELC), Code 220, as the block-funded program manager. The objective of the SEM 6.2 development program is to build on the established and proven SEM concept by providing:

1. Functions for additional application areas
2. Increased module functionality
3. Module application support

- Functional interface definition and system application guidelines.
- Detailed electrical, mechanical, thermal, and environmental interface definitions for a new standard module.
- Support hardware (back panel, card cage, enclosure, and rack/cabinet concepts).

It is intended that the 6.2 development concepts will be carried through prototype hardware via an Advanced Development (6.3) program to be initiated during FY 1977. Figure 1 provides the major milestone schedule for the overall SEM R&D Program.

The Naval Avionics Facility, Indianapolis (NAFI) and the Naval Weapons Support Center (NWSC), Crane were assigned the task of developing an advanced SEM package. The objective of this task is to identify and develop a family of standard electronic module configurations with controlled electrical, mechanical, and thermal interfaces which will be compatible with large electronic functions having multisystem commonality. In addition, this family of modules is to be compatible with a variety of higher level packages, including enclosures, racks, and cabinets. These higher level package

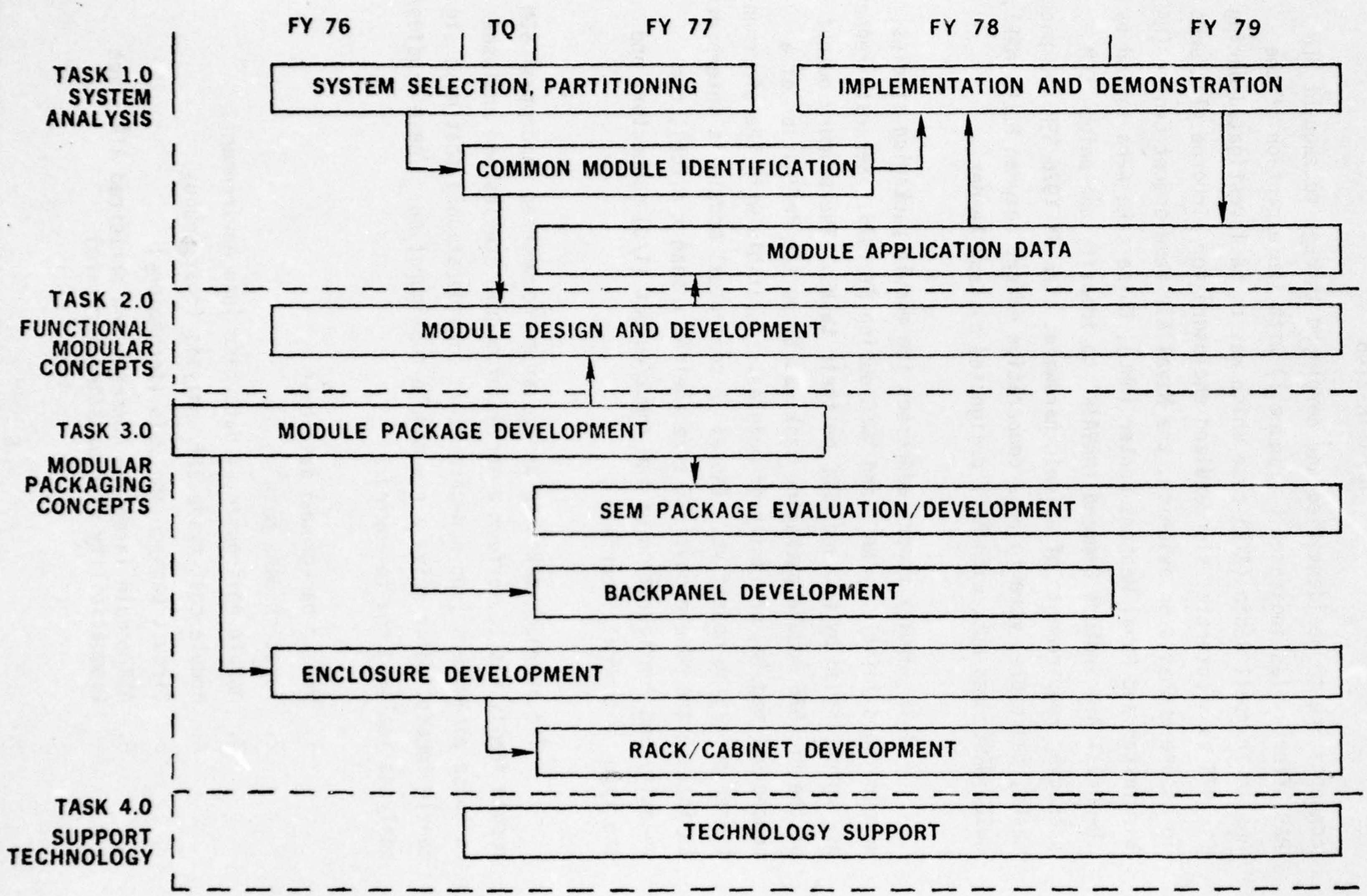


Figure 1. SEM R&D Program Schedule

concepts are to be identified and developed through subsequent SEM R&D efforts, (as indicated by Figure 1) with the exception of the Austin Trumbell Radio (ATR) case which was to be investigated during FY 1976 as a potential standardized enclosure for airborne platforms. To assure emphasis on avionics, the Naval Air Development Center (NADC), Warminster and Naval Weapons Center (NWC), China Lake were tasked by the Naval Air Systems Command (NAVAIR) to identify the unique SEM packaging requirements of avionic hardware. The FY 1976 SEM R&D packaging tasks, therefore, were to be a cooperative effort between NELC, NAFI, NWSC, NADC, and NWC, with NAFI designated as task leader.

This summary report addresses the module packaging studies accomplished jointly by NAFI and NWSC during FY 1976. Separate reports are being issued by NWC and NADC on their tasks. The primary output of the FY 1976 module packaging task was to be the definition of a conceptual module, or family of modules, compatible with the aforementioned packaging objective. (Note: A conceptual module is interpreted to include the module physical size (height x span x pitch), the quantity and configuration of the input/output (I/O) connector, and the type of thermal interface.)

The approach taken to arrive at a recommended conceptual SEM module family was to perform a series of module studies and analyses on those parameters (and non-parametric considerations) that most significantly impact and/or drive a new module configuration. These studies/analyses included the following:

1. Module background data base
2. Function data base
3. Module environmental data base (use environment)
4. Module cost trade-off analysis (cost bounds)
5. Circuit package analysis (technology)
6. ATR/module interface concepts and preferred ATR sizes (compatibility with existing hardware)

In order to apply a structured and objective engineering approach to the process of defining a recommended conceptual SEM module family, trade-off criteria and data reduction techniques were developed. Using this process, five conceptual modules were identified as candidate modules. Trade-off analyses were then performed on these conceptual modules to arrive at a recommended conceptual module family. Figure 2 provides a flow diagram indicating the described approach.

Numerous working papers/reports have been generated during FY 1976 pertaining to the detailed module studies performed. This report summarizes the data and conclusions from these working papers/reports, provides the resulting candidate conceptual module definition, summarizes the analyses performed on these modules and the conclusions resulting, and provides the overall module package conclusions and recommendations resulting from the packaging studies performed to date.

Current industry studies related to definition of a standard module family were used in support of the module studies reported herein. See References B, C, D, E, and F.

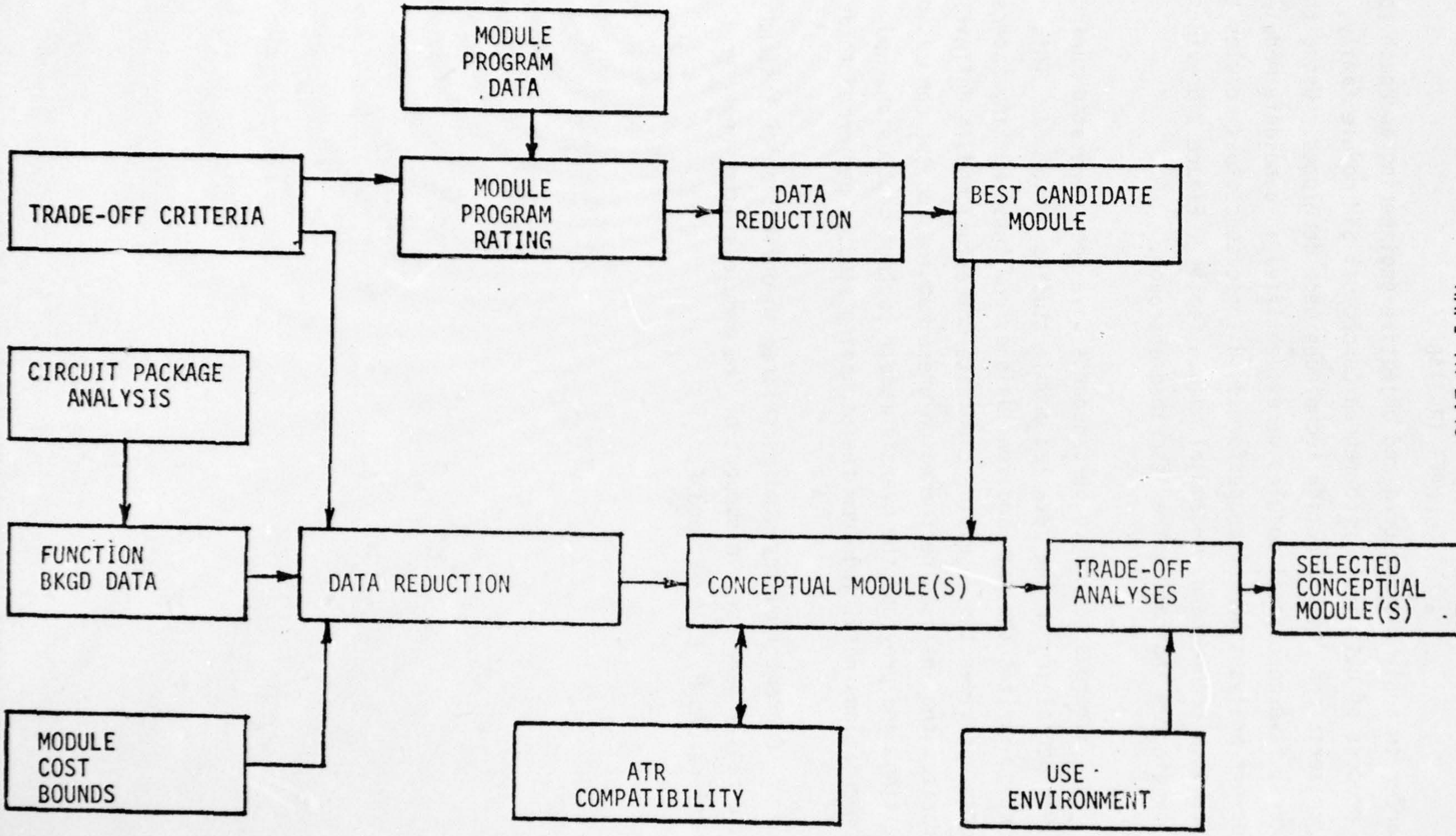


Figure 2. SEM R&D MODULE DEVELOPMENT APPROACH

IV. DETAILED STUDIES

A. TECHNOLOGY

The objective of this task is to examine current and projected (1975 - 1980 time frame) commercial microelectronic device packaging technologies to determine their impact on a module standardization concept. Main emphasis has been on digital devices with a limited examination of discrete analog components.

Two circuit board "footprints" were developed for each component. One, based on a 0.1 x 0.1 inch grid for multilayer board interconnections (MIB), and one which used the rule of thumb criteria of approximately two times the component area. Component descriptions and their footprints are tabulated in Appendix A. These data were used where applicable in the other tasks.

Figure 3 is a bar graph showing the relative component heights and is useful in establishing minimum module thickness.

Dimensional data were taken from MIL-M-38510, MIL-R-39008, MIL-C-55681, MIL-R-27208, and when not available as a military specification, from industry literature.

Table 1 shows the upper limit for thermal resistances of packages based on MIL-M-38510. These we believed to be unnecessarily pessimistic and not compatible with high density, high reliability packaging. Table 2 shows the lowest junction to case thermal resistance ratings from industry and Table 3 shows the thermal ratings based on findings at NWSC Crane when evaluating thermal analysis procedures for determining the junction to case thermal resistance of a variety of semiconductor devices. For thermal analysis, junction to case thermal resistances of 45°C and 25°C per watt were used for 14 - 16 pin flatpack and DIP packages respectively.

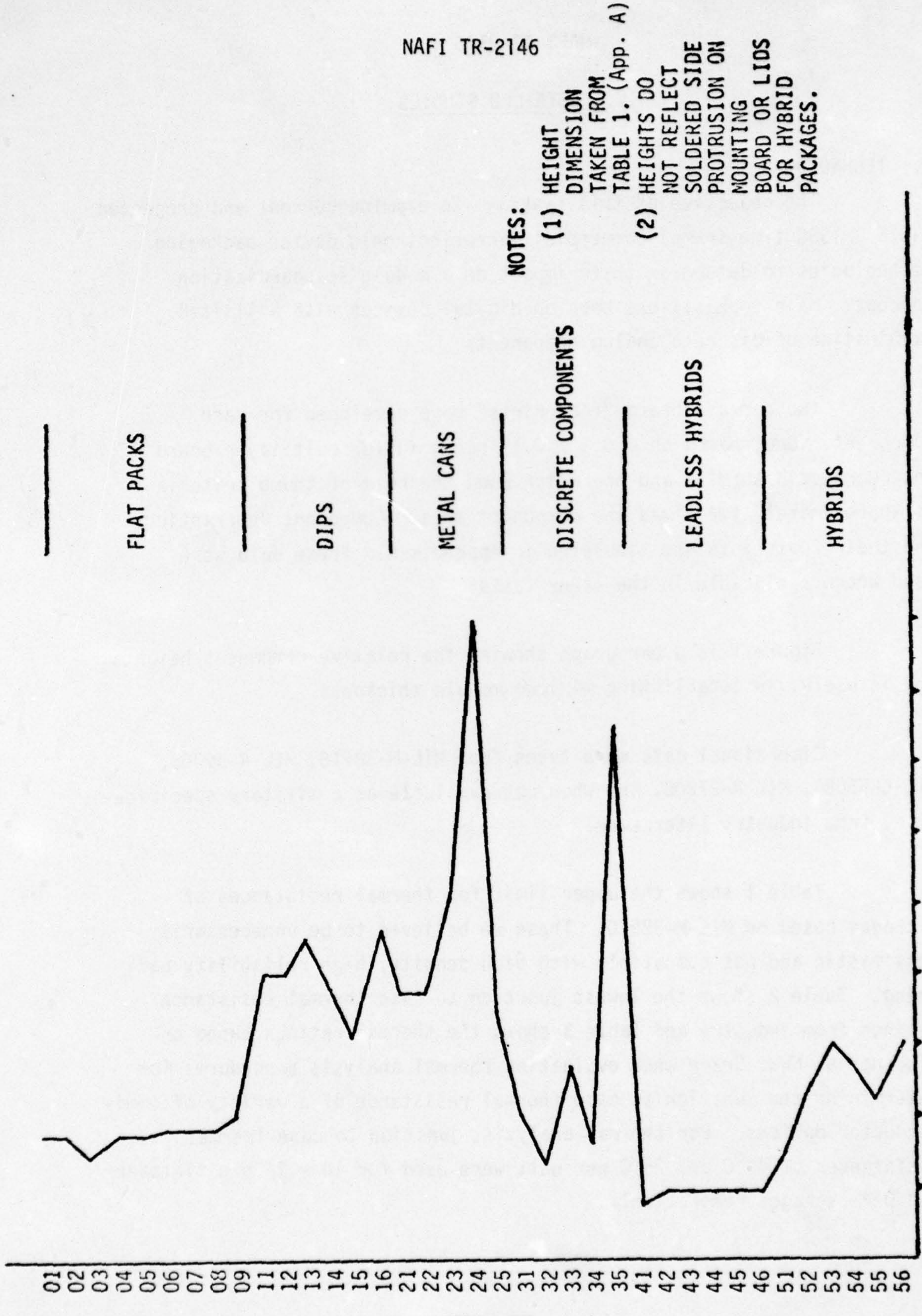


Figure 3. Component Height Comparison

Projected future usage of the packages examined results in the prioritized listing in Table 4. It appears that DIP packages will be more widely used than flatpacks. Availability, cost, and the ability to use automatic insertion assembly equipment are the reasons for industry preference for DIP packaged devices. (See Reference B)

Table 1. Maximum Thermal Ratings (MIL-M-38510)

PACKAGE	θ_{JC} °C/W	θ_{JA} °C/W	T_J °C
14-16p F.P.	90 (150)	140	175
14-16p DIP	80	120	175
24p F.P.	40	85	175
24p DIP	13	85	175
(A1) 8p TO-5	40	150	175
(A2) 10p TO-5	40	140	175
(X) 3p TO-5	15	150	275
(Y) TO-3	2	35	275

Table 2.

Lowest Junction to Case Thermal Ratings from Industry

PACKAGE	θ_{JC} °C/W
14-16p F.P.	43
14-16p DIP	24
24p F.P.	44
24p DIP	10
TO-5	15
TO-3	.5

Table 3. Thermal Ratings (NWSC Crane)

PACKAGE	θ_{JC} °C/W
14p Flatpack	35
14-16_p DIP	25
TO-5 Can	20

Table 4. Prioritized List of Packages

DIPS	14p-16p
	24p
	28p
	40p
FLATPACKS	14p-16p
	24p
	40p
METAL CANS	TO-5
	TO-3
	TO-8
HYBRIDS	
LEADLESS HYBRIDS	

B. MODULE BACKGROUND

The objective of this task is to present information on a variety of existing electronic modules which are being employed or developed within both industry and the military. This information is intended for use as an aid in the selection and design of a proposed Standard Electronic Module for tri-service applications. The intent of the data contained herein is not to be all-inclusive, but to provide a basic understanding of the module status, physical aspects, and mechanical features.

Data were obtained for each module program listed in Table 5. Table 5 describes the module developer or controlling activity for each module included in the survey. Table 6 is a composite data summary matrix derived from the detailed data.

The data contained in the composite summary matrix of Table 6 was analyzed to develop a list of major advantages and disadvantages. These advantages/disadvantages are relative to characteristics of all modules considered in the survey. Table 7 lists the major advantages/disadvantages for each module program.

Table 5. Electronic Module Survey Listing

Module Program	Developer (Controlling Activity)
SEM 1A	(Naval Electronic Systems Command)
SEM 2A	(Naval Electronic Systems Command)
QED	Naval Electronics Laboratory Center San Diego, California
ARPS	General Electric Company Utica, New York
MK 5	MIT Draper Labs, Cambridge, Massachusetts
ML-1	IBM Federal Systems Division Owego, New York
4 π	IBM Federal Systems Division Owego, New York
AEGIS	RCA, Camden, New Jersey
MK 86	Lockheed Missile & Space Corporation Plainfield, New Jersey
F-15	Hughes Aircraft Company Culver City, California
SAM-D	Raytheon Company, Bedford, Massachusetts
XN-1 (AADC)	(Naval Air Systems Command)

TABLE 6. Module Summary

MODULE	TOTAL MODULE SIZE THICK	SPAN	HT.	PITCH	ACTIVE PACKAGE SIZE THICK	SPAN	HT.	NUMBER OF CONNECTOR PINS	TYPICAL WT. (LB)
SEM 1A	.290	2.620	1.950	.300	.290	2.20	1.00	40	.055
SEM 2A	.290	5.620	1.950	.300	.290	5.10	1.00	100	.100
QED	.290	5.620	4.950	.300	.290	5.10	4.00	80	.270
ARPS	.560	10.800	7.000	.600	.460	6.70	5.40	300	1.250
MK 5	.292	3.570	3.060	.300	.292	3.29	2.55	60	.150
ML-1	.450	7.460	3.505	.460	.450	6.60	2.40	240	.500
4 π	.440	8.000	3.150	.460	.440	6.75	2.10	196	.500
AEGIS	.280	4.350	3.800	.300	.280	3.80	2.70	70	.100
MK 86	.300	3.600	3.700	.300	.300	3.40	2.75	58	.070
F-15	.400	6.900	5.500	.500	.325	6.00	4.50	200	.500
SAM-D	.280	6.500	3.830	.300	.280	6.00	2.60	112	.290
XN-1	.475	4.000	4.000	.500	.300	4.00	2.75	292	.450
F-14	.350	6.300	5.900	.400	.350	5.80	5.00	100	.500

TABLE 6. Module Summary (Cont.)

MODULE	DEVICE COMPATIBILITY	NO. BOARDS PER MODULE	NO. LAYERS PER BOARD	CALCULATED NO. OF COMPONENTS PER MODULE	METHOD OF COOLING	MAX. SPECIFIED POWER (WATTS)
SEM 1A	All types except full wafer LSI	1 or 2	Up to 6	16 Flats 5 DIPS	Conduction to Top Fin and Side Guides	3
SEM 2A	All types except full wafer LSI	1 or 2	Up to 6	40 Flats 12 DIPS	Conduction to Top Fin and Side Guides	5
QED	All types except flatpacks and full wafer LSI	1 Only	Stitch Weld	48 DIPS	Direct Air	10
ARPS	All types except DIPS	2 Only	10 - 14	338 Flats	Hollow Card Air Hx	65
MK 5	All types except full wafer LSI and DIPS	2 Only	6	72 Flats	Conduction to Side Guides	10
ML-1	All types except full wafer LSI	1 or 2	12	156 Flats 32 DIPS	Conduction to Top Surface	22
4 π	All types except DIPS and full wafer LSI	2 Only	12	130 Flats	Conduction to EARS	18
AEGIS	All types except DIPS and full wafer LSI	1 Only	2 - 4	42 Flats	Direct Air	5.25
MK 86	All types except full wafer LSI	1 Only	2	36 Flats	Direct Air	Unknown
F-15	All types except DIPS	2 Only	6	132 Flats	Hollow Card Air Hx	30
SAM-D	All types except DIPS/LSI	1 Only	4 - 6	72 Flats	Direct Air	,20
XN-1	All types except DIPS	1 or 2	4 - 6	80 Flats	Hollow Card Air Hx	40 (for LSI wafer)
F-14	All types except full wafer LSI	1 Only	8	70 DIPS	Conduction to Side Guides	12

TABLE 6 Module Summary (Cont.)

MODULE	MODULE ASPECT RATIO	ACTIVE CKT BOARD ASPECT RATIO	PINS PER IN^2 ACTIVE CIRCUIT BRD AREA	# OF MOD PINS PER IC (DIPS)	# OF MOD PINS PER IC (FLATS)	ACTIVE CKT VOLUME / TOTAL VOLUME	TOTAL VOL. (IN^3)/IC (DIPS)	TOTAL VOL. (IN^3)/IC (FLATS)	MOD WT(LB) / TOTAL VOL.	MOD WT. (LB) PER IC (DIPS)	MOD WT. (LB) PER IC (FLATS)	INSERTION/ EXTRACTION FORCE (LB)
SEM 1A	.74	.45	18.20 1 brd 9.1 2 brd	8.00	2.50	.43	.296	.093	.037	.011	.0034	12
SEM 2A	.35	.20	19.60 1 brd 9.8 2 brd	8.33	2.50	.47	.265	.080	.031	.0092	.0023	30
QED	.88	.78	3.92 1 brd	1.70	-	.73	.170	-	.033	.0056	-	24
ARPS	.65	.81	4.15 2 brd		.89	.39	-	.125	.033		.0041	35 - 40
MK 5	.86	.78	3.56 2 brd		.83	.77	-	.044	.047		.0042	18
ML-1	.47	.36	15.15 1 brd 7.58 2 brd	7.50	1.54	.61	.370	.075	.042	.013	.0032	40 - 60
4 *	.39	.31	6.91 2 brd		1.51	.56	-	.085	.045		.0038	40 - 60
AEGIS	.87	.71	6.82 1 brd		1.67	.62	-	.110	.022		.0024	20
MK 86	1.03	.81	6.20 1 brd		1.66	.70	-	.110	.018		.0019	18
F-15	.81	.75	3.70 2 brd		1.52	.59	-	.113	.033		.0038	45
SAM-D	.59	.43	7.18 1 brd		3.11	.63	-	.097	.042		.0040	35
XN-1	1.00	.69	26.54 1 brd 13.27 2 brd		3.65	.43	-	.095	.059		.0056	0
F-14	.94	.86	3.45 1 brd	1.43	0.76	.78	.186	.077	.038	.0071	.0038	25

TABLE 7

MAJOR ADVANTAGES/DISADVANTAGES

MODULE PROGRAM	ADVANTAGES	DISADVANTAGES
SEM 1A	* Good Cooling Flexibility and Mechanical Application Flexibility * Can Package Booth DIPS and Flatpacks * Functionally Specified * Good Producibility * Good Incremental Growth Capability	* Small Number of Connector I/O Pins * Low Volumetric Packaging Efficiency
SEM 2A	* Can Package Both DIPS and Flatpacks * Functionally Specified * Good Cooling Flexibility * Low Weight per Flatpack Ratio	* Low Circuit Board Aspect Ratio * Low Volumetric Packaging Efficiency
QED	* High Volumetric Packaging Efficiency * Low Total Volume per DIP Ratio * Low Weight per DIP Ratio	* Low Ratio of I/O Pins to Active Circuit Board Area * Not Designed to Package Flatpacks * Shock/Vibration Resistance Poorer Than Most
ARPS	* Large Number of Connector I/O Pins * Heat Exchanger Integral with Module * Good Shock/Vibration Characteristics	* High Ratio of Total Volume per Flatpack * Inability to Package DIPS * Minimal Cooling/Mechanical Application Flexibility * Poor Incremental Growth Flexibility * Poorer Producibility Than Most * Low Volumetric Packaging Efficiency
MK 5	* Has High Volumetric Packaging Efficiency * Has Low Ratio of Total Volume per Flatpack	* Inability to Package DIPS * Small Number of Connector I/O Pins * Low Ratio of I/O Pins to Active Circuit Board Area * Low Ratio of I/O Pins per Flatpack

TABLE 7 (CONTINUED)

MAJOR ADVANTAGES/DISADVANTAGES

MODULE PROGRAM	ADVANTAGES	DISADVANTAGES
ML-1	* Can Package Both DIPS and Flatpacks * Large Number of Connector I/O Pins * Good Shock/Vibration Characteristics	* Top Mounted Cold Plate Hinders Maintainability * Connector Grid Matrix Not Compatible with 0.1" Wire Wrap Grid * Poorer Producibility Than Most * High Ratio of Total Volume per DIP
4 ▾	* Good Shock/Vibration Characteristics * Large Number of Connector I/O Pins	* Inability to Package DIPS * Connector Grid Matrix Not Compatible with 0.1" Wire Wrap Grid * Poorer Producibility Than Other Edge Cooled Modules
AEGIS	* Low Weight to Total Volume Ratio * Low Weight per Flatpack Ratio * Good Producibility	* Poor Shock/Vibration Resistance * Poor Cooling Flexibility * Inability to Package DIPS * Poor Mechanical Application Flexibility * Connector Grid Matrix Not Compatible with 0.1" Grid Wire Wrap
MK 86	* Good Producibility * Low Weight to Total Volume Ratio * Low Weight per Flatpack Ratio	* Poor Shock/Vibration Resistance * Poor Cooling Flexibility * High Aspect Ratio * Small Number of Connector I/O Pins * Poor Mechanical Application Flexibility
F-15	* Large Number of Connector I/O Pins * Heat Exchanger Integral with Module	* Inability to Package DIPS * Poor Incremental Growth Flexibility * Poorer Producibility Than Most * Low Ratio of I/O Pins to Active Circuit Board Area

TABLE 7 (CONTINUED)

MAJOR ADVANTAGES/DISADVANTAGES

MODULE PROGRAM	ADVANTAGES	DISADVANTAGES
SAM-D	* High Ratio of Number I/O Pins per Flatpack * Conduction Cooling Thru Guides Possible * Good Environmental Flexibility	* Inability to Package DIPS * Individual Frame Support and Heat Sink Hinders Producibility Somewhat
XN-1	* Large Number of Connector I/O Pins * Heat Exchanger Integral with Module * High Ratio of I/O Pins per Flatpack * Zero Insertion Force * High Ratio of I/O Pins to Active Circuit Board Area * Good Shock/Vibration Resistance Probable	* Inability to Package DIPS * Poor Cooling Flexibility * Poor Mechanical Application Flexibility * Use of Edge Card Contacts * Connector Grid Matrix Not Compatible with 0.1" Wire Wrap * Poor Incremental Growth Flexibility * Poorer Producibility Than Most * Required Module/Air Plenum Interface Hinders Maintainability * Low Volumetric Packaging Efficiency * High Ratio of Weight per Flatpack
F-14	* High Volumetric Packaging Efficiency * Low Total Volume per DIP Ratio	* Low Ratio of I/O Pins to Active Circuit Board Area * Low Ratio of I/O Pins per DIP * High Aspect Ratio * Use of Edge Card Contacts * Not Designed to Package Flatpacks, Although Possible

C. FUNCTION BACKGROUND

The objective of the Function Background subtask is to determine the optimum module physical parameters for packaging those existing functions which have demonstrated or have potential for intersystem commonality. The specific parameters to be recommended are active circuit area, number of pins and power dissipation capability.

1. Data Collection Approach

The approach used was to compile data from existing standard functions and conceptual standard functions. Functions were selected according to the following ground rules.

a. Functions selected were to have either demonstrated or be projected to have intersystem or intrasystem commonality.
b. Selections were made to avoid duplications of functions within the data base.
c. Functions which required custom or proprietary hybrid microcircuits in order to be packaged in the specified modular configuration were not selected.
d. Unit logic functions (integrated circuits used on modules without inter-microcircuit connections) were selected at the highest level of standardization whenever duplication occurred between standard function module programs.

All known modular standardization programs as well as several individual systems which used the same modular functions multiple times were analyzed. A listing of module programs and systems from which the current data base was derived is included as Figure 4.

A multiple page worksheet was completed for each function detailing the circuitry required, technology used, performance, circuit area required, connector pins required, power dissipated, power supply requirements, method of partitioning, and electrical interface.

Program	Developer
AEGIS	RCA
CNC	UNIVAC
BRN-5	MAGNAVOX
4 π	IBM
SEM 1A	NAVELEX
SEM 2A	NAVELEX
SAM-D	RAYTHEON
QED	NELC
MARK 86	LOCKHEED
WSC-2 *	NELC
MIMC *	NELC

* Projected Future Functions

Figure 4. Module Programs Included

2. Methods of Data Reduction

Data for approximately 200 total functions were tabulated and a data base was established from 83 functions which were selected according to the ground rules itemized above.

Graphical representation of the data was accomplished by plotting the number of functions in the data base which could be packaged versus each of the critical modular packaging parameters.

For example, consider Figure 5 which is the graph for the dual-in-line package (DIP) packaging area parameter. Area requirements for specific components were taken from the results of the Technology subtask. The areas do not include the space required for inter-package clearance or for electrical interconnections on the printed wiring board (PWB). The total circuit card area can be calculated from the component footprint area by assuming 50 to 60% efficiency for packaging components on double-sided PWBs and 70 to 80% efficiency for packaging on multilayer interconnection boards (MIBs).

From Figure 5 it is seen that a module which provides 11.0 IN^2 of footprint area could package 95% (or 79) of the 83 functions in the data base using DIPs. This would indicate that approximately 14.6 IN^2 (11.0 IN^2/0.75) of total PWB area would be required assuming use of a 75% efficient MIB.

Figure 6 presents a similar analysis based on packaging data base functions using flatpack packages.

Figure 7 presents the number of the 83 functions which can be packaged for a specific number of module connector pins. The number of pins includes signal, power, and ground pins.

Figure 8 gives the relationship between the maximum power dissipation capability of a module and its effectiveness in packaging data base functions.

A summary of circuit card area computations based on packaging with both DIPs and flatpacks assuming 70% and 80% efficient area utilization is included in Figure 9.

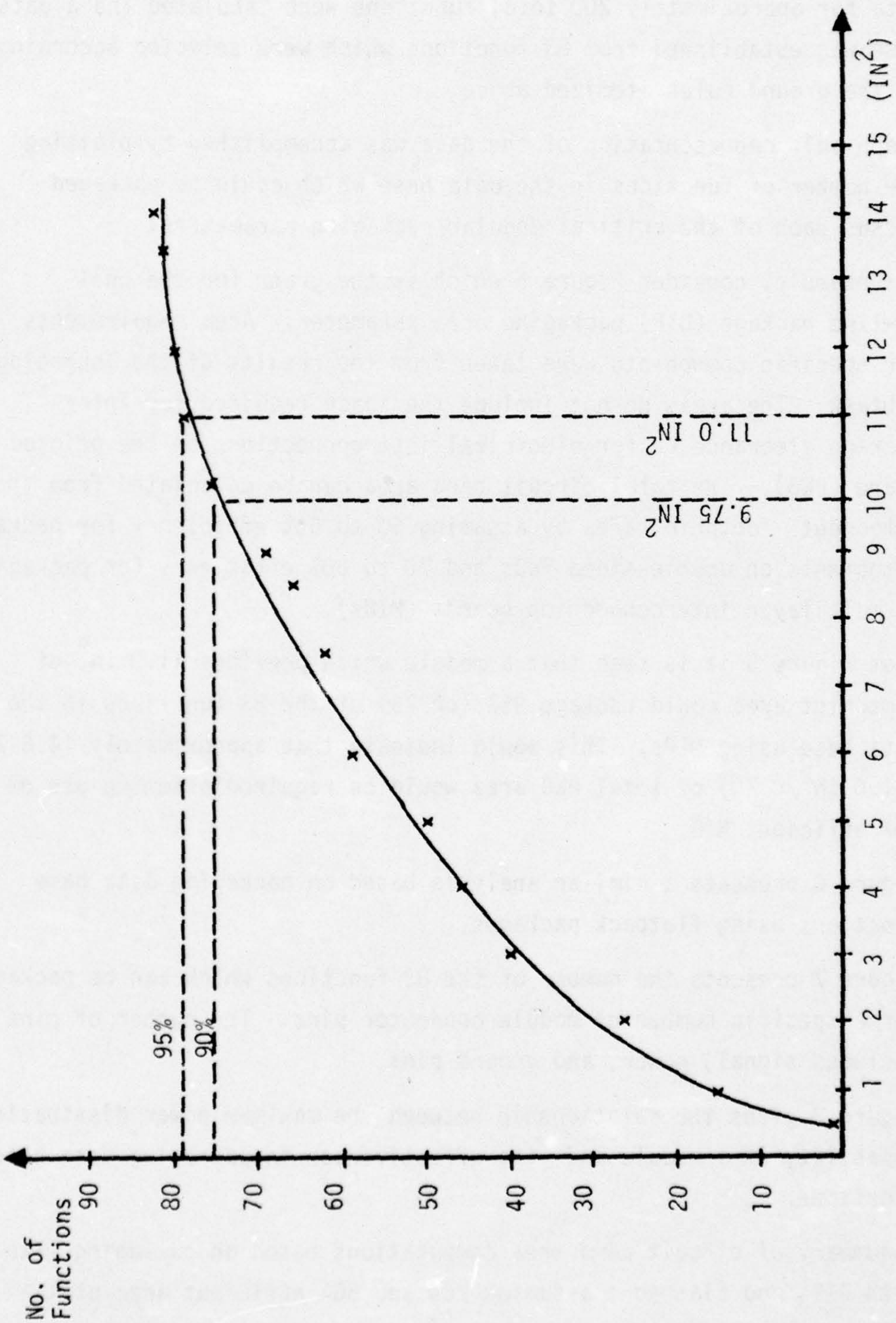


Figure 5. Dual-In-Line Component Footprint ... Integrated Curve

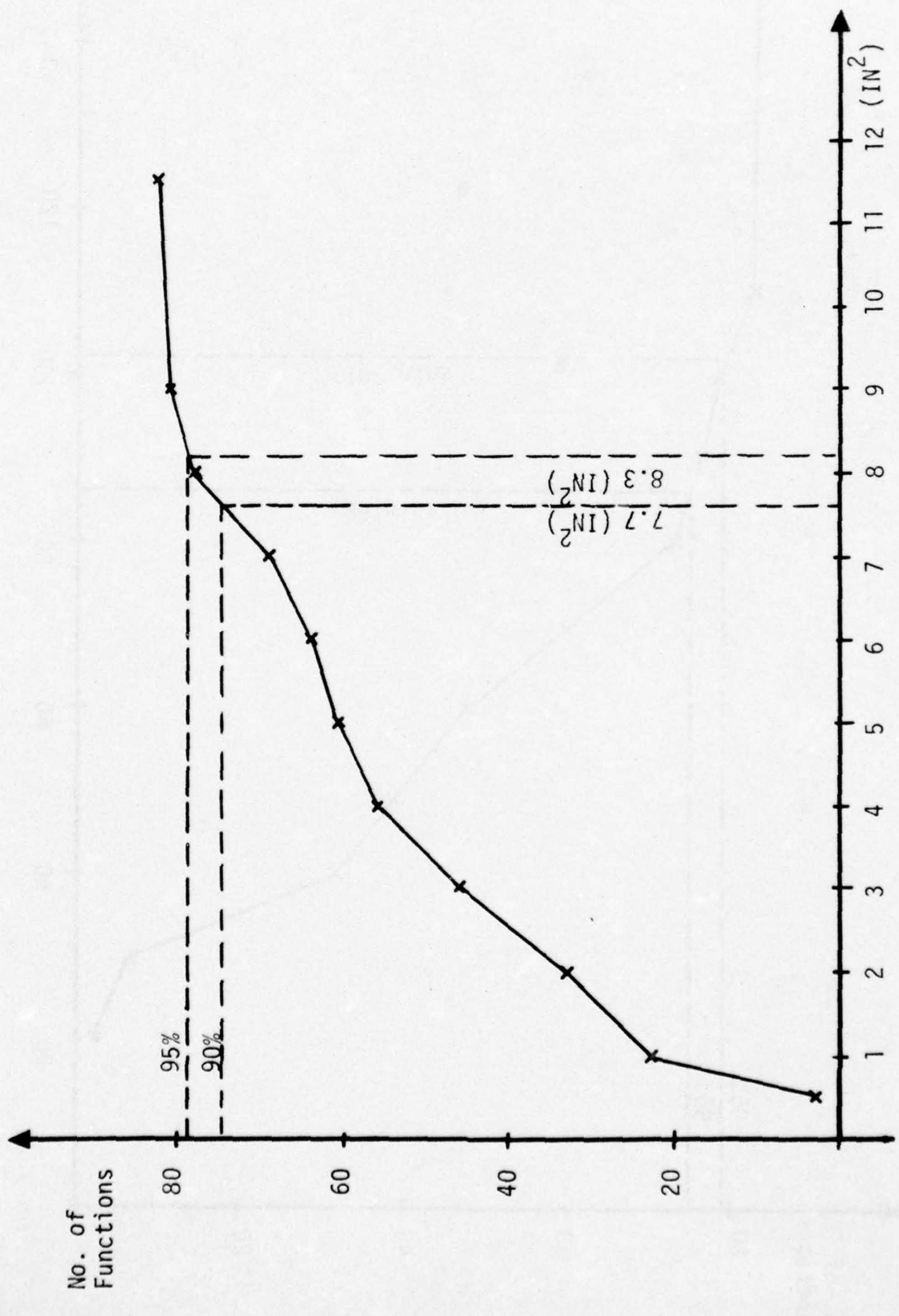


Figure 6. Flatpack Footprint ... Integrated Curve

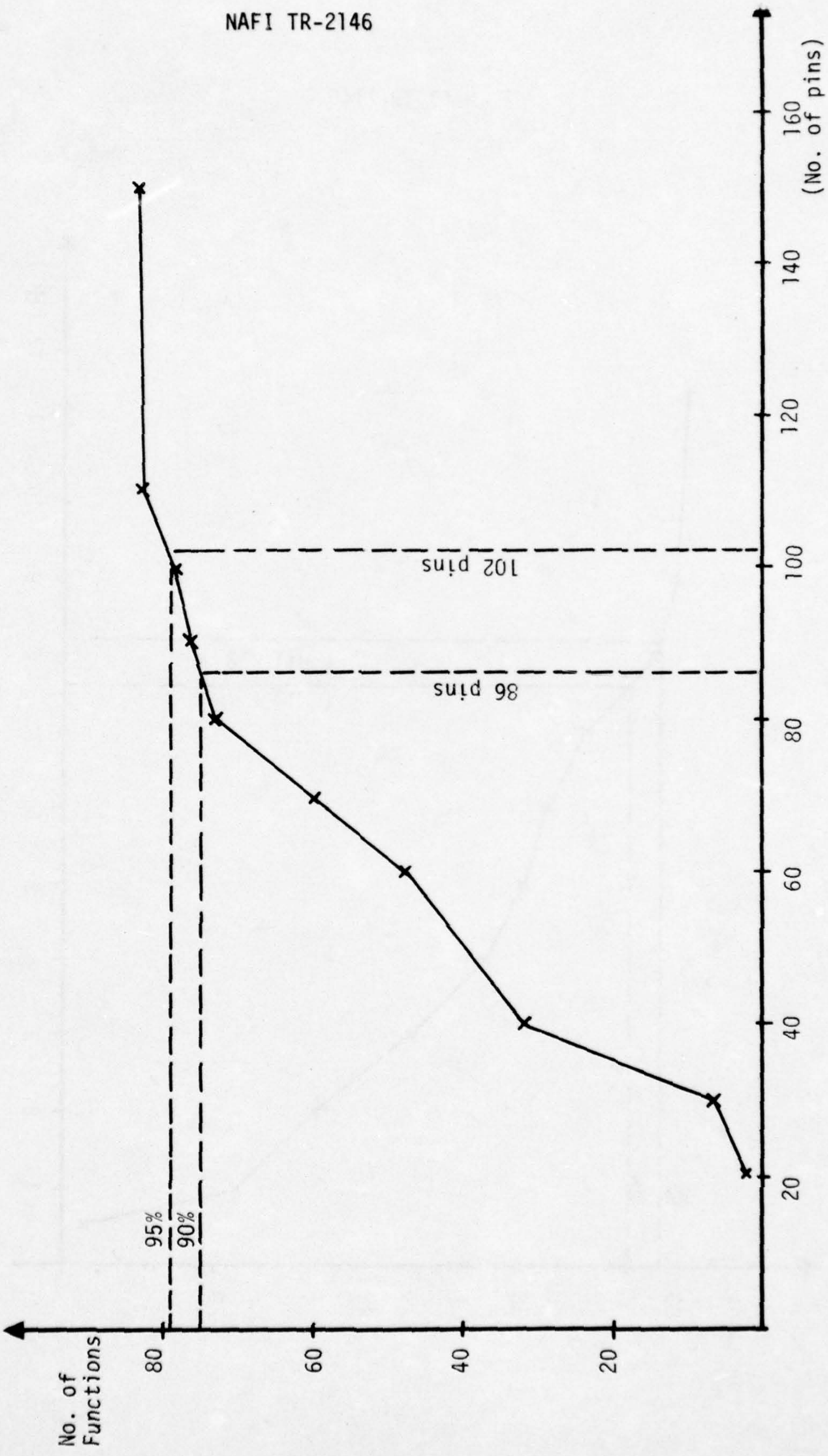


Figure 7. Pins Required ... Integrated Curve

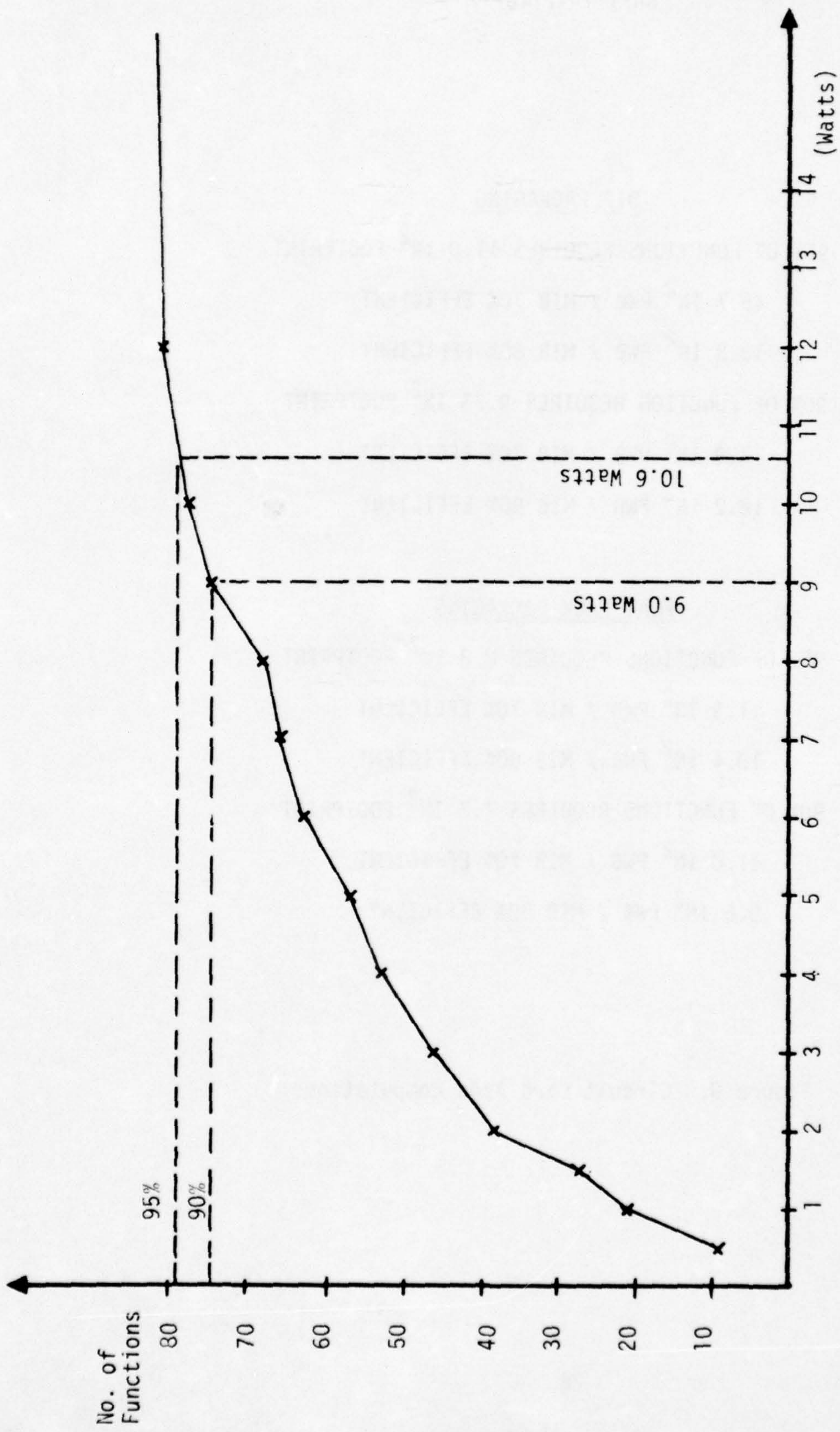


Figure 8. Maximum Power ... Integrated Curve

DIP PACKAGING

95% OF FUNCTIONS REQUIRES 11.0 IN^2 FOOTPRINT

15.7 IN^2 PWB / MIB 70% EFFICIENT

13.8 IN^2 PWB / MIB 80% EFFICIENT

90% OF FUNCTION REQUIRES 9.75 IN^2 FOOTPRINT

13.9 IN^2 PWB / MIB 70% EFFICIENT

12.2 IN^2 PWB / MIB 80% EFFICIENT

FLAT PACK PACKAGING

95% OF FUNCTIONS REQUIRES 8.3 IN^2 FOOTPRINT

11.9 IN^2 PWB / MIB 70% EFFICIENT

10.4 IN^2 PWB / MIB 80% EFFICIENT

90% OF FUNCTIONS REQUIRES 7.7 IN^2 FOOTPRINT

11.0 IN^2 PWB / MIB 70% EFFICIENT

9.6 IN^2 PWB / MIB 80% EFFICIENT

Figure 9. Circuit Card Area Computations

3. Conclusions

The following conclusions regarding module parameters are derived directly from the Function Background subtask data.

a. A module which provides a maximum of 13.8 IN^2 to 15.7 IN^2 of circuit card area will package 95% of existing and projected standard functions using DIPs.

b. For high density applications the same functions could be packaged on a module with a 10.4 IN^2 to 11.9 IN^2 of circuit card area using flatpack microcircuit packages.

c. This module must also provide approximately 100 connector pins for signals, power, and ground in order to package 95% of the functions.

d. The module should be capable of dissipating 10.6 watts of maximum power.

D. ATR ENCLOSURE COMPATIBILITY

The objective of this task is to determine the compatibility of present and proposed SEM with ATR enclosures per ARINC Specification 404A. (See Reference G.)

The constraints placed on module mechanical dimensions by the various ATR enclosures were determined with the four module orientations shown in Figure 10. Allowances were made for enclosure and module support structures; cold plate cooling; air ducts; module interconnection back-panel; enclosure connector; and interconnections between the backpanel and enclosure connector.

The following assumptions were made in order to determine mechanical constraints:

Mechanical:

1.	ATR structural wall thickness, inches	0.09
2.	ATR dust cover thickness, inches	0.03
3.	Connector length inside rear of ATR, inches	1.08
4.	Space for wire harness for ATR connector, inches	0.75
5.	Minimum allowable module width, inches	2.62
6.	Minimum allowable module height, inches	1.89
7.	Module thickness, inches	0.3
	Note: The module envelope is defined as the maximum external dimensions shown in Figure 11.	
8.	Module connector is on only one edge of module.	
9.	Total case dimensional tolerance stack-up allowance, inches	0.12
10.	Short ARINC Specification 404A ATR cases are primary considerations. Dimensions are shown in Figure 12.	

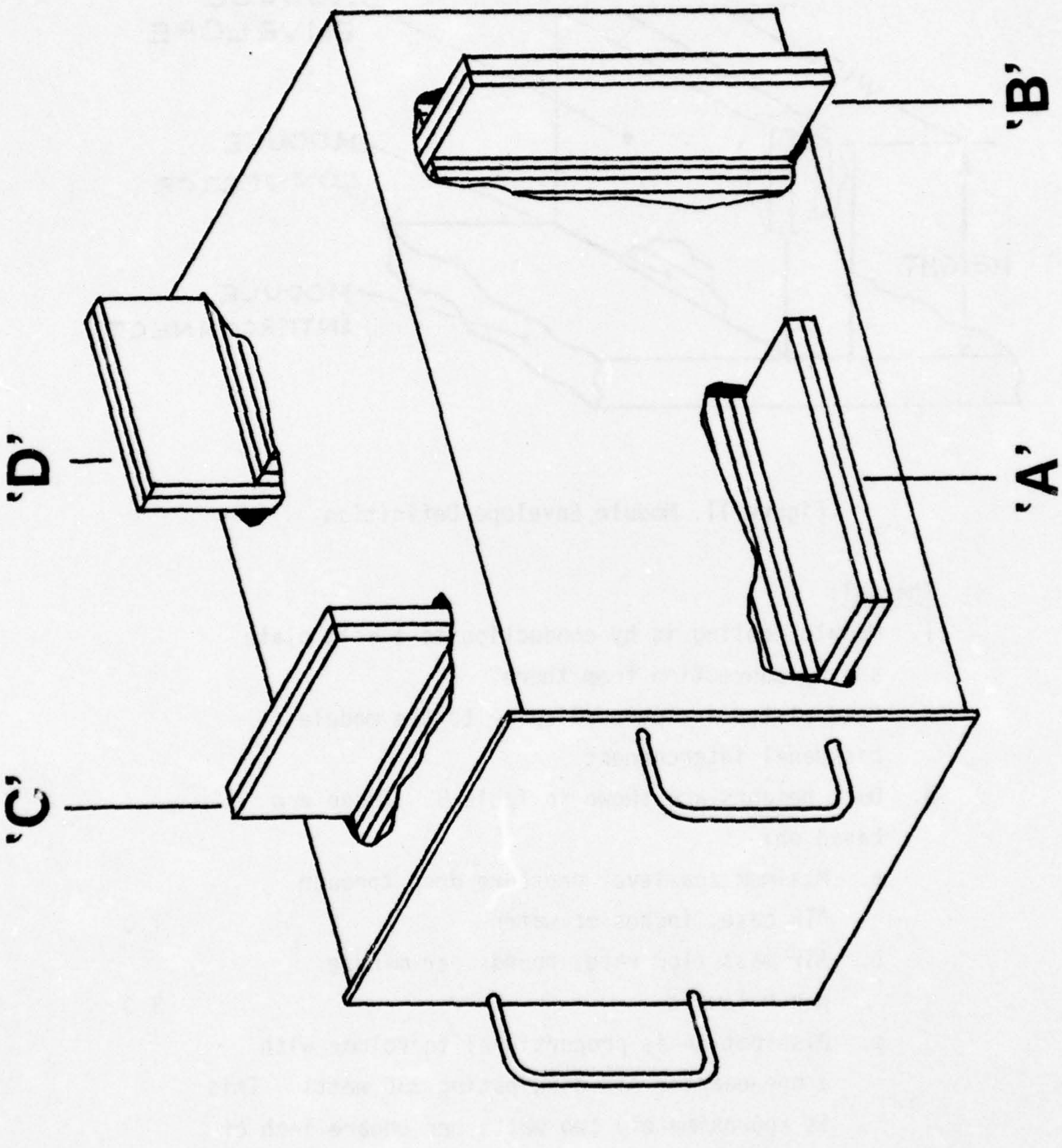


Figure 10. Module Orientation

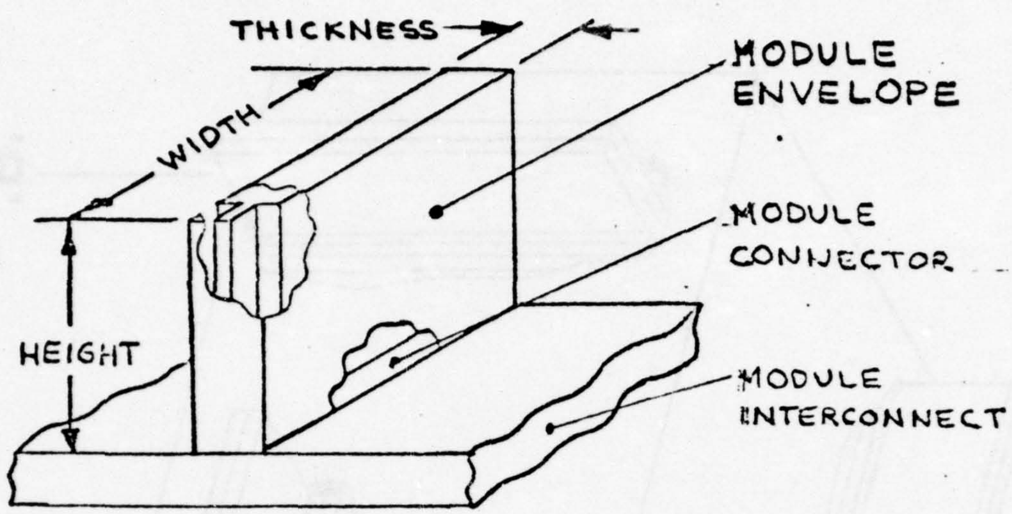
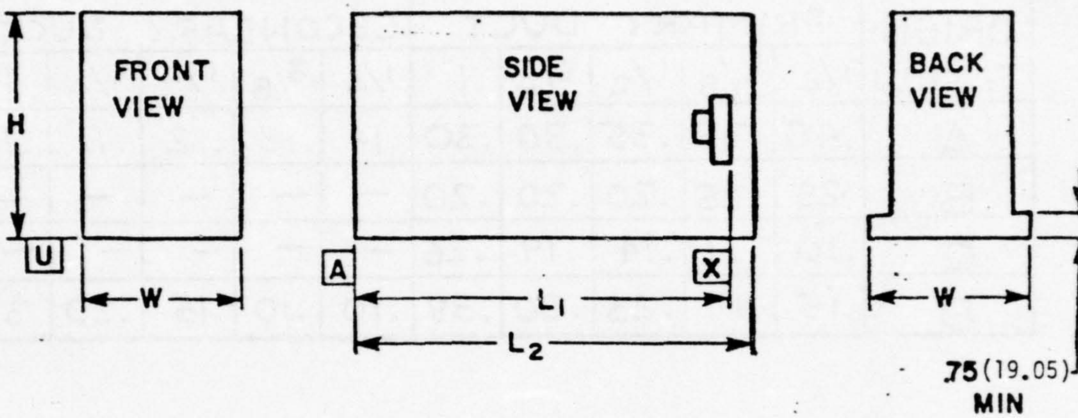


Figure 11. Module Envelope Definition

Thermal:

1. Module cooling is by conduction to a cold plate and by convection from there.
2. Cold plates are perpendicular to the module backpanel interconnect.
3. Duct heights are shown in Table 8. These are based on:
   a. Maximum sea level pressure drop through ATR case, inches of water 1.0
   b. Air mass flow rate, pounds per minute per kilowatt 3.0
   c. Dissipation is proportional to volume with a one-quarter ATR dissipating 230 watts. This is approximately two watts per square inch of circuit board and 2.5 watts per square inch of module to cold plate interface area.



ATR SIZE	Approx Vol.		W		L_1		L_2 (Max)		H(Max)	
	In^3	Liter	±.03in	±.76mm	±.04in	±1.0mm	in	mm	in	mm
Dwarf	95	1.56	2.25	57.15	12.52	318.0	12.62	320.5	3.38	85.8
1/4 Short	215	3.52	2.25	57.15	12.52	318.0	12.62	320.5	7.62	193.5
1/4 Long	335	5.49	2.25	57.15	19.52	495.8	19.62	498.3	7.62	193.5
3/8 Short	340	5.57	3.56	90.41	12.52	318.0	12.62	320.5	7.62	193.5
3/8 Long	530	8.69	3.56	90.41	19.52	495.8	19.62	498.3	7.62	193.5
1/2 Short	470	7.70	4.88	123.95	12.52	318.0	12.62	320.5	7.62	193.5
1/2 Long	725	11.88	4.88	123.95	19.52	495.8	19.62	498.3	7.62	193.5
3/4 Short	720	11.80	7.50	190.50	12.52	318.0	12.62	320.5	7.62	193.5
3/4 Long	1120	18.36	7.50	190.50	19.52	495.8	19.62	498.3	7.62	193.5
1 Short	975	15.98	10.12	257.05	12.52	318.0	12.62	320.5	7.62	193.5
1 Long	1510	24.75	10.12	257.05	19.52	495.8	19.62	498.3	7.62	193.5
1 1/2	2295	37.62	15.38	390.65	19.52	318.0	19.62	498.3	7.62	193.5

Figure 12. Basic Dimensions of Standard ATR Cases

ORIEN-TATION	PRIMARY DUCT					SECONDARY DUCT				
	1/4	3/8	1/2	3/4	1	1/4	3/8	1/2	3/4	1
A	.40	.35	.35	.30	.30	.14	.13	.12	.11	.10
B	.25	.25	.20	.20	.20	—	—	—	—	—
C	.10	.11	.14	.19	.26	—	—	—	—	—
D	.15	.17	.23	.30	.38	.10	.10	.15	.20	.30

Table 8. Cold Plate and Air Plenum Duct Height for ATR Cases, Inches

Module Interconnection:

Figure 13 shows the module backplane interconnection dimensions for wire-wrap with two and three wrap levels; a wrapost plate with a multilayer printed circuit board; and an integral connector backplane multi-layer printed circuit board.

Maximum Module Envelopes

Table 9 lists the maximum allowable module envelopes after deducting cooling, interconnect, and structure space from the ATR volume using the assumptions given above. Up to three module rows were used in defining the module widths and up to two module layers were used in defining the module heights. The subscripts on W and H in Table 9 refer to the number of rows and layers respectively.

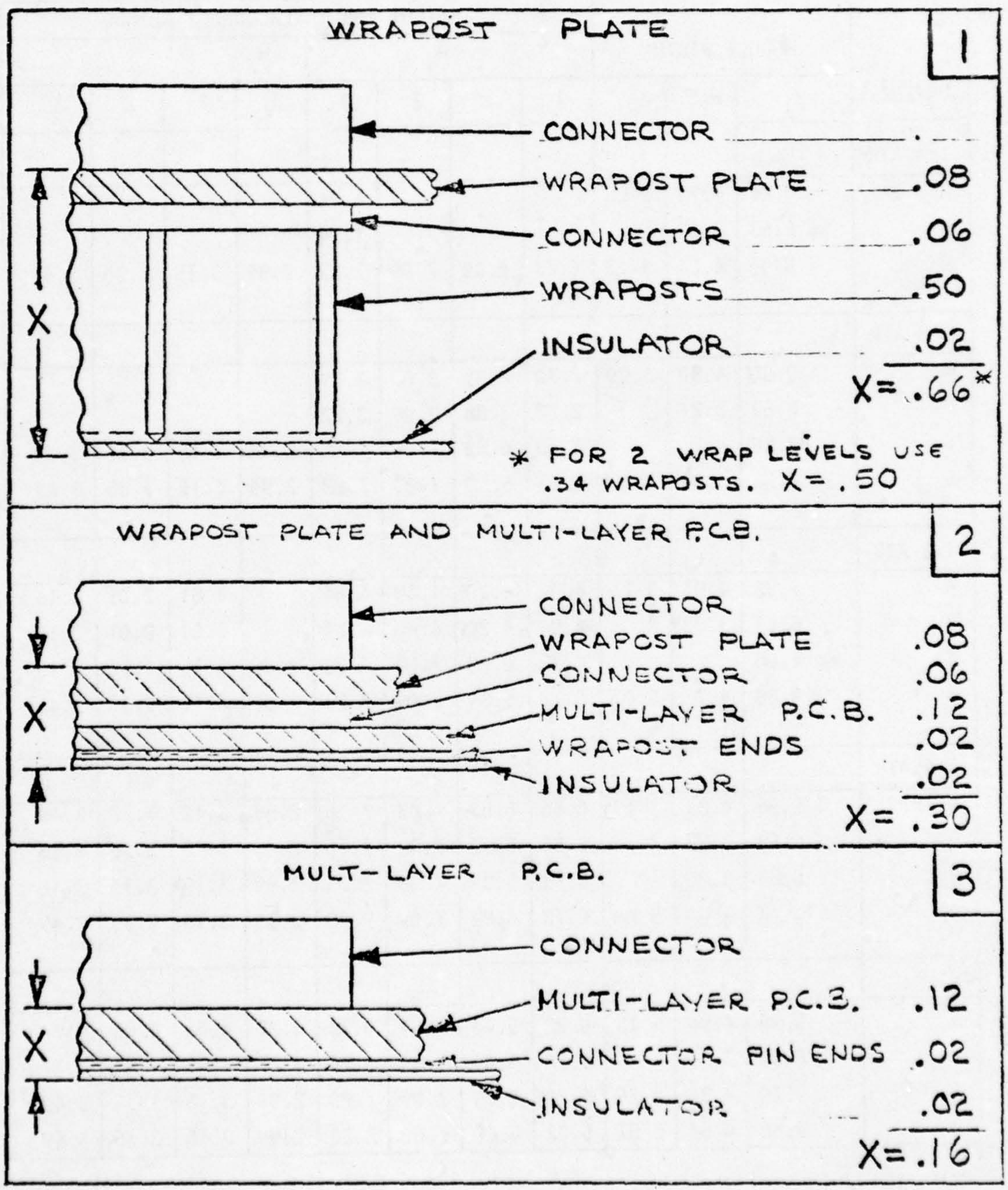


Figure 13. Module Interconnection

Table 9. Module Envelopes

ORIENT.	MODULE WIDTH			MODULE HEIGHT FOR INTERCONNECT METHOD							
				H_1				H_2			
	W_1	W_2	W_3	1	1*	2	3	1	1*	2	3
1/4 ATR											
A	10.06	4.78	3.08				1.94				
B	6.53	3.23					1.94				
D	9.96	4.84	3.13	6.73	6.89	7.09	7.23	2.99	3.15	3.35	3.49
3/8 ATR											
A	9.90	4.80	3.09	2.72	2.88	3.08	3.22				
B	6.53	3.27		2.72	2.88	3.08	3.22				
C	2.80			6.73	6.89	7.09	7.23	2.99	3.15	3.35	3.49
D	9.96	4.84	3.13	6.73	6.89	7.09	7.23	2.99	3.15	3.35	3.49
1/2 ATR											
A	9.92	4.81	3.11	4.04	4.20	4.40	4.54		1.81	2.01	2.15
B	6.63	3.22		4.04	4.20	4.40	4.54		1.81	2.01	2.15
C	4.06			6.73	6.89	7.09	7.23	2.99	3.15	3.35	3.49
D	9.86	4.77	3.07	6.73	6.89	7.09	7.23	2.99	3.15	3.35	3.49
3/4 ATR											
A	9.96	4.84	3.13	6.66	6.82	7.02	7.16	2.96	3.12	3.32	3.46
B	6.63	3.22		6.66	6.82	7.02	7.16	2.96	3.12	3.32	3.46
C	6.58	3.20		6.73	6.89	7.09	7.23	2.99	3.15	3.35	3.49
D	9.76	4.69	3.00	6.73	6.89	7.09	7.23	2.99	3.15	3.35	3.49
1 ATR											
A	9.96	4.84	3.13	9.28	9.44	9.64	9.78	4.27	4.43	4.63	4.77
B	6.63	3.22		9.28	9.44	9.64	9.78	4.27	4.43	4.63	4.77
C	9.10	4.34	2.75	6.73	6.89	7.09	7.23	2.99	3.15	3.35	3.49
D	9.56	4.54	2.87	6.73	6.89	7.09	7.23	2.99	3.15	3.35	3.49

As would be expected, orientation A and D have nearly the same allowable module widths for all short ATR cases. Orientations C and D have the same allowable module height for all ATR cases for a given interconnect method.

From Table 9 it is observed that orientation D gives the greatest module envelope compatibility with all ATR cases and orientation C gives the least compatibility. Orientation A and B have virtually equal module envelope compatibility with all ATR cases, but the volume efficiency of using the ATR cases will vary with ATR case size for a fixed module envelope.

It is interesting to note that a 9.10W x 6.73H module for the full ATR with orientation C is also compatible with all other short ATR cases with orientation D.

It should also be noted that an approximately 3 x 3 module with incremental growth to approximately 9 x 6 is feasible.

Relative figures-of-merit for module and ATR case packaging are shown in Table 10. These figures-of-merit consist of ratios of the active circuit board area, ATR case volume, and cold plate/module interface (projected) area with all dimensions used in inches. Key to the chart is shown at the bottom. Interconnection and orientation are defined the same as in Table 9.

Mean values for all orientations are shown at the bottom of Table 10. The board area to ATR volume ratio increases with module size while the cold plate area to board area ratio decreases with module size. The power density capability as indicated by the cold plate area to ATR volume ratio is relatively independent of module size.

Table 10. Module/ATR Packaging Figures of Merit

MOD.	C1			C2	Improved SEM			Present SEM		
INTRC.	1	2	3	3	1	2	3	1	2	3
SIZE ORIENT.										
1/4 A							1.06 .26 .28			.81 .33 .27
B							1.09 .18 .20			.84 .24 .20
C										
D			.99 .24 .24					.28 .67 .19		
3/8 A			1.43 .19 .27		.67 .41 .27	→		.51 .54 .28	→	
B			1.48 .14 .21		.68 .30 .20	→		.53 .38 .20	→	
C								.46 .89 .41	→	
D			1.12 .21 .24					.36 .60 .22	→	
1/2 A	1.04 .27 .28	→					.98 .29 .28			.75 .38 .28
B	1.07 .19 .20	→					1.01 .21 .21			.77 .27 .21
C				1.40* .21 .29				.34 .89 .30	→	
D			1.17 .19 .22					.42 .54 .23	→	
				xx xx xx						

Top xx: $\frac{\text{Board Area}}{\text{ATR Volume}}$

Lower left xx: $\frac{\text{Cold Plate Area}}{\text{Board Area}}$

Lower right xx: $\frac{\text{Cold Plate Area}}{\text{ATR Volume}}$

* ½ Span

Table 10. Module/ATR Packaging Figures of Merit (Continued)

MOD.	C1			C2	Improved SEM			Present SEM		
INTRC.	1	2	3	3	1	2	3	1	2	3
SIZE ORIENT.										
3/4 A			1.35 .21 .28		.63 .45 .28	→	→	.49 .58 .28	→	→
B			1.40 .15 .20		.65 .32 .21	→	→	.50 .42 .21	→	→
C			1.40 .14 .20					.50 .39 .20	→	→
D			1.24 .19 .24					.45 .54 .24	→	→
1 A	1.00 .28 .28	→	→				.94 .30 .28			.72 .40 .29
B	1.03 .20 .21	→	→				.96 .22 .21			.74 .28 .21
C				1.63 .09.24				.54 .27 .14	→	→
D			1.26 .19 .24					.46 .54 .25	→	→
Σ/N			1.11 .18 .21	1.52 .15.26			.86 .24 .24			.56 .32 .24
					xx xx xx					

$\frac{\text{Board Area}}{\text{ATR Vol.}}$

$\frac{\text{Cold Plate Area}}{\text{ATR Vol.}}$

$\frac{\text{Cold Plate Area}}{\text{Board Area}}$

E. THERMAL EVALUATION

The objective of this task is to classify, characterize, and evaluate the thermal performance of the various modules surveyed under the module background task. Due to the simplified thermal models used for evaluation, they should not be used as a design guide.

The method of analysis described herein should be construed only as a means for comparison of cooling techniques and overall thermal capacities. The cooling methods analyzed for each module were generally restricted to those methods intended for use by the original module program/system application.

A total of thirteen modules were surveyed and analyzed using data gathered from the cognizant module developers. Table 11 lists the modules which were considered for analysis and the source of existing thermal data. Table 12 classifies the cooling methods characteristic of the module programs and defines the specific cooling methods intended for each module program in the form of a matrix. It should be noted that all possible cooling techniques for each module were not exploited due to the limited scope of this task and that the cooling method matrix in Table 12 was not intended to reflect the cooling versatility for any specific module.

Simplified thermal models were developed for each of the cooling methods defined in Table 12. These models are shown in Figures 1 through 5 of Appendix E. In order to establish a common baseline for comparison of module thermal performance, the following assumptions were made:

1. Inlet temperature of coolant fluid = $40^{o}C$.
2. Maximum device junction temperature = $115^{o}C$.
3. Junction-Case thermal resistance for DIPS = $25^{o}C/W$ (representative of ceramic DIPS with gold eutectic die bond)
4. Junction-Case thermal resistance for flatpacks = $45^{o}C/W$ (representative of metal case flatpacks with gold eutectic die bond)
5. All modules are populated with the maximum number of IC's calculated from available board packaging area and device footprint

Table 11. Thermal Data Source Listing

MODULE/PROGRAM	DATA SOURCE
* SEM 1A	NAVWPNSUPPCEN Crane, Indiana
* SEM 2A	NAVWPNSUPPCEN Crane, Indiana
** F-14	Hughes Aircraft Company (Ivan Jones) Culver City, California
** F-15	Hughes Aircraft Company (Ivan Jones) Culver City, California
** MK 5	MIT Draper Labs (Geo. Lamantea) Cambridge, Massachusetts
** 4 π	IBM Corporation (Bruno Pagnani) Owego, New York
* ML-1	IBM Corporation (Bruno Pagnani) Owego, New York
* ARPS	General Electric Company (Rod Mogle) Utica, New York
* QED	General Electric Company (Ron Bauer) Pittsfield, Massachusetts
* SAM-D	Raytheon Company (Joe Sisio) Bedford, Massachusetts
* XN-1	Naval Avionics Facility (Mike Stowe) Indianapolis, Indiana
*** MK 86	NAVWPNSUPPCEN Crane, Indiana
** AEGIS	RCA (Henry Inacker) Camden, New Jersey

* Thermal Report Submitted to NAVWPNSUPPCEN Crane
** Data Received by Fonecon
*** Data Not Available; AEGIS Data Utilized

Table 12. Cooling Methods

I. Direct Air Impingement

II. Conduction; Convection From Module Fin

III. Conduction; Convection From Cold Plate

A. Top of Module

B. Both Sides of Module (Water Cooling for SEM 1A, SEM2A, QED, & MK 5)

IV. Hollow Card

COOLING METHOD MATRIX

MODULE	I	II	IIIA	IIIB	IV
SEM 1A		*		*(H_2O)	
SEM 2A		*		*(H_2O)	
MK5				*(H_2O)	
4 π				*	
ML-1			*		
F-15					*
ARPS					*
QED	*			*(H_2O)	
MK 86	*				
AEGIS	*				
SAM-D	*				
XN-1					*
F-14				*	

( ) Indicates Heat Sink Fluid if Different from Air

(reference Appendix A, Table 1; package style 03 for 14 pin flatpacks and package style 12 for 16 pin DIPs).

6. All modules can accommodate component packaging densities achieved by multilayer board interconnection technology (densities utilizing roughly 65-75% of available active circuit board packaging area).

7. All modules are uniformly powered (i.e. power dissipated per device is a constant).

8. Flow rates of the coolant fluid (judged to be representative of the intended module cooling applications) are as follows:

a. Cooling Method I - volumetric air flow rate is 2 ft^3/minute and air velocity is 10 ft/sec.

b. Cooling Method II - volumetric air flow rate is 2 ft^3/minute and air velocity is 20 ft/sec.

c. Cooling Method IIIA, IIIB, and IV - air mass flow rate is 3.0 lb/minute/kilowatt through cold plate heat exchanger with fin stock from 10-13 fins per inch.

d. Cooling Method IIIB (water only) - water volumetric flow rate is 1.2-1.4 gallons/minute/kilowatt.

Based upon the above assumptions, the thermal capacity of each module was calculated using the thermal resistance values supplied by each module developer. (The thermal resistance values supplied were characteristic of pseudo worst case conditions, such as hot spot to frame reference.) The overall thermal capacity was expressed as a conductance, $Q/\Delta T = K$, where ΔT is the temperature rise from the coolant fluid to the maximum allowable junction temperature. Each module was evaluated using dual in-line packages (DIPs) and/or flatpacks (flats), depending on the compatibility of the module configuration in accommodating these packages. The conductance per unit of total module volume, K/V, was determined for each module and the results showing the relative thermal capacities of the modules are in Figure 14.

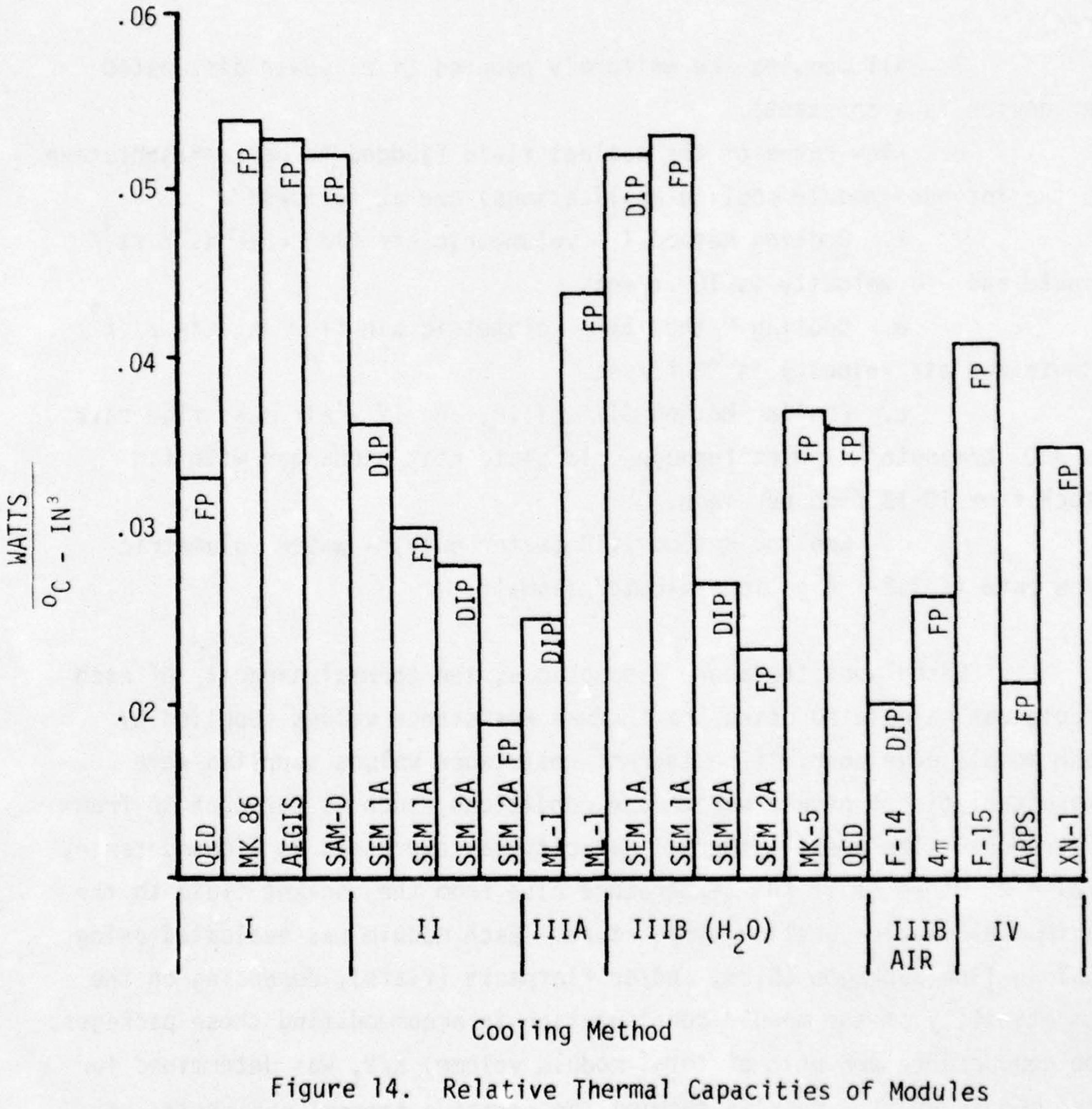


Figure 14. Relative Thermal Capacities of Modules

The power density values were calculated from the K/V values and are shown in Figure 15. These data are valid for a 40^{o}C heat sink fluid temperature and a maximum junction temperature of 115^{o}C in addition to the other assumptions made above. The conductance per unit volume (K/V) was based upon the total envelope volume for each module. Table 13 is a prioritized list of cooling effectiveness based on total power per unit volume. Dual in-line packages and flatpacks are considered independently so that comparisons can easily be made. Again, it must be realized that this analysis does not exploit all possible cooling methods for each module and this prioritized listing in Table 13 is only valid for the cooling methods considered.

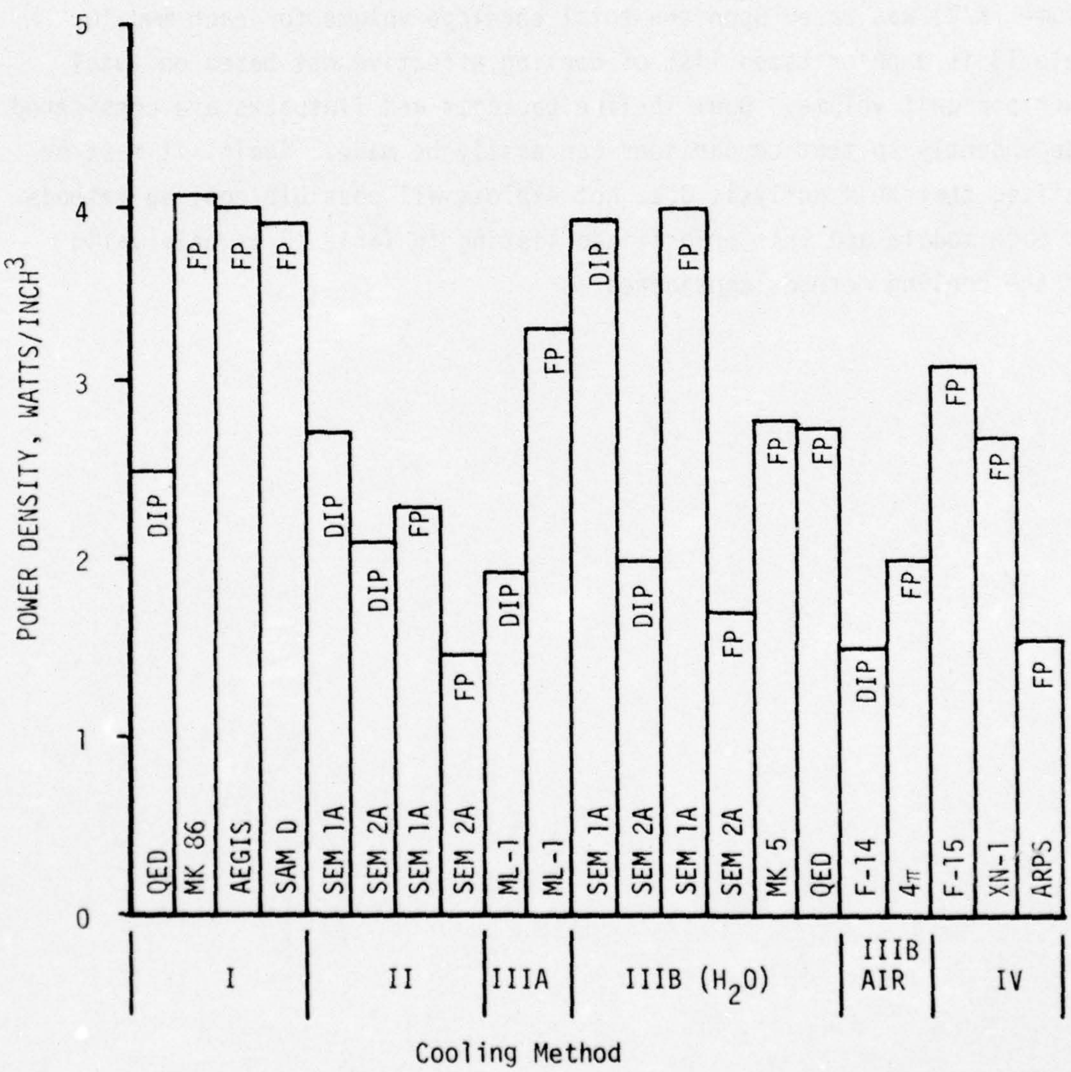


Figure 15. Relative Cooling Effectiveness

Table 13. Prioritized Module Cooling Effectiveness

Dual In-Line Packages

Module	Method	Power Density (W/IN^3)
SEM 1A	IIIB(H_2O)	3.93
SEM 1A	II	2.72
QED	I	2.50
SEM 2A	II	2.11
SEM 2A	IIIB(H_2O)	2.00
ML-1	IIIA	1.89
F-14	IIIB(AIR)	1.49

Flat Packs

Module	Method	Power Density (W/IN^3)
MK 86	I	4.03
SEM 1A	IIIB(H_2O)	3.99
AEGIS	I	3.94
SAM-D	I	3.89
ML-1	IIIA	3.27
F-15	IV	3.07
MK 5	IIIB(H_2O)	2.76
QED	IIIB(H_2O)	2.74
XN-1	IV	2.65
SEM 1A	II	2.26
4 π	IIIB(AIR)	1.97
SEM 2A	IIIB(H_2O)	1.70
ARPS	IV	1.56
SEM 2A	II	1.45

F. COST BOUNDS

Objective of the cost bounds task is to develop upper boundary cost trade-offs for proposed SEM modules.

Selected typical hypothetical module operational scenario data were used in a life cycle cost model to show the cost trade-offs.

The spare flow model used, Figure 16 assumes there are N_E equipments receiving good modules from each base. In turn M bases are supplied by a depot.

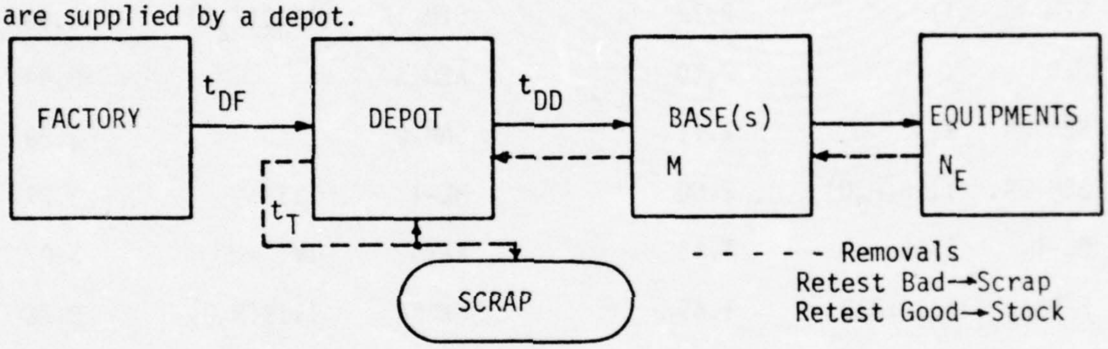


Figure 16. Spare Module Flow

Only one depot is assumed. The depot in turn is supplied by one or more factories. Both depot and bases are assumed to have only spares to assure a given probability of meeting the spare requirement during their replenishment time. The replenishment time for a depot is t_{DF} and for a base t_{DD}. Good modules flow from factory to depot to base to equipment. Modules which are removed from equipment flow back to the depot via a base. At the depot removed modules are tested and those testing good are returned to base with a depot delay time of t_T plus twice the depot to base delay time t_{DD}.

For the purpose of the mathematical model the bad removed modules are assumed to be discarded at the depot. In actual practice either failure analysis or repair and return to stock could occur. There is sufficient overlap between module acquisition and repair costs

that it will be necessary to look at specific individual module types at a given time to resolve the advantages of repair vs. throwaway of bad modules.

For a given case variation, all modules making up a system are assumed to have the same number of 14 or 16 pin integrated circuits each having the same failure rate and cost. All module types are assumed to have the same system population. A constant failure rate with time has been assumed.

The mathematical model used is given by:

$$\frac{R}{N_{IC}} = (1+K_L)K_{OC}\lambda_{IC}\left[(1+2K_{GB})t_{DD} + K_{GB}\,t_T + t_{DF} + t_L\right]$$

$$+ E_x\sqrt{\frac{N_T}{N_E N_D}\,(1+1K_L)K_{OC}\lambda_{IC}}\left[\sqrt{(1+2K_{GB})t_{DD} + K_{GB}\,t_T} + \sqrt{\frac{t_{DF}}{M}}\right] \quad (12)$$

A definition of the terms in equation 12 is given in Appendix B.

The possible combinations of parameters over their ranges give an extremely wide variation of values for equation 12. By taking typical hypothetical cases which are comparable to expected widely used SEM systems, meaningful results can be obtained using equation 12.

Table 14 shows parameters for cases representative of submarine (1) and (2), surface ship (3), and high performance aircraft (4), sub-systems.

Case 1 is an idealization of an existing system with averaged actual field failure rates. These systems are used on long patrols.

Case 2 is an idealization of a newer system currently under-development which is similar to Case 1 with more complex integrated

Table 14. Typical Hypothetical System Cases

CASE	1 (SUB)	2 (SUB)	3 (SHIP)	4 (AIR)
t_L, System Life	87,600.	87,600.	87,600.	87,600.
t_{DD}, Depot Delay	2,160.	2,160.	720.	720.
t_T, Test Delay	168.	168.	168.	168.
t_{DF}, Factory Delay	4,000.	4,000.	4,000.	4,000.
K_L, Induced Failures	1	1	1	1
N_E, No. Equip.	1	1	1	20
M, No. Bases	31	10	14	2
N_D, IC's/Equip.	17,200.	21,000.	1,000.	752
N_T, No. Types	20.	20.	20.	20.
R, Spare Ratio	0.1	0.1	0.1	0.1
K_{GB}, Retest Good	0.5	0.8	0.5	0.5
λ_{IC} (FIELD)	10^{-8}	$2x10^{-7}$ (Extra-polated)		$2.45x10^{-7}$
λ_{IC} (60% CONF.)				$4.895x10^{-7}$
λ_{IC} (90% CONF.)				$9.54x10^{-7}$
λ_{IC} (217B)			$2.x10^{-7}$	
λ_{IC} (RADC-TR-67-108)		$0.8x10^{-6}$		$1.287x10^{-6}$
π_E	0.2	0.2	4.	4.
K_{OC}, Operating Ratio	1.	1.	0.33	0.0571

NOTE: PROBABILITY OF ADEQUATE SPARES ASSUMED TO BE 0.98

circuits operating at higher junction temperatures. Its failure rates are extrapolated from Case 1.

Case 3 is typical of any number of small to moderate sized subsystems for surface ship applications. A thirty day replenishment time for ships store is assumed in contrast to the 90 days assumed for Cases 1 and 2.

The failure rate of Case 3 is based on prediction by Mil-HDBK-217B of a similar complexity system.

Case 4 uses the Heads Up Display of the F-15 aircraft to establish the number of integrated circuits and a number of failure rates both actual and predicted.

All cases assume six months depot replenishment delay by the factory for spares. Cases 1 and 2 are assumed to operate 24 hours per day; Case 3 operates 8 hours per day; and Case 4 operated 500 hours per year.

The ratio of spares per module, R, during the life cycle of all systems is assumed to be 0.1, i.e. life cycle spare costs is 10% of system operating module acquisition cost. Ten percent was used since this is approximately the border line between a relatively insignificant cost and a significant cost. It was also justified on the basis that spares cost needs to be less than the thirty percent which has been achieved and considered excessive in some instances. Another rational for the ten percent choice is that the spare life cycle cost is approximately proportional to failure rates and failure rates have relatively large standard deviations. A nominal R ratio greater than 0.1 could have disasterous life cycle cost impact for modules in the upper range of the failure rate distribution curve.

The hypothetical system cases listed in Table 14 were analyzed using equation 12 with failure rate of the integrated circuits as a variable to find the number of integrated circuits per module which would cause the ratio of spares per module to be 0.1.

Figure 17 and Table 15 show the results with the expected failure rate point plotted as a large dot on each case curve on Figure 17.

Table 15. Number of Integrated Circuits Per Module for 0.1 Ratio of Spares and 0.98 Probability of Adequate Spares

CASE	IC FAILURES/ HOURS	NUMBER OF IC/ MODULE
1 (SUB)	10^{-8}	32 *
2 (SUB)	2×10^{-7}	2
3 (SHIP)	2×10^{-7}	5
4 (AIR)	9.5×10^{-7}	8

* 36 If 0.9 Probability of Adequate Spares, no change for cases 2, 3, and 4.

A comparison of acquisition cost of electronic modules, for a given notional system, derived from vendor sell prices for different quantities of differently packaged modules is shown in Figure 18. While the dollars per integrated circuit slot for some other system may differ significantly from that shown, the relative cost for the different packaging schemes should remain approximately the same. It should be noted that commonality is more important than size. The SEM special module is approximately 2 x 3 inches and falls on the same line as a 6 x 8 module while a SEM standard is approximately one third the cost for the same number of integrated circuit slots.

Life cycle cost significantly depends on the number of integrated circuits per module and their failure rate. It also depends on the functional commonality of modules within and between systems. Predicted integrated circuit failure rates would indicate that five to 10 circuits per module is the boundary of spares cost significance. Lack of commonality can result in a three to one increase in the acquisition cost of modules.

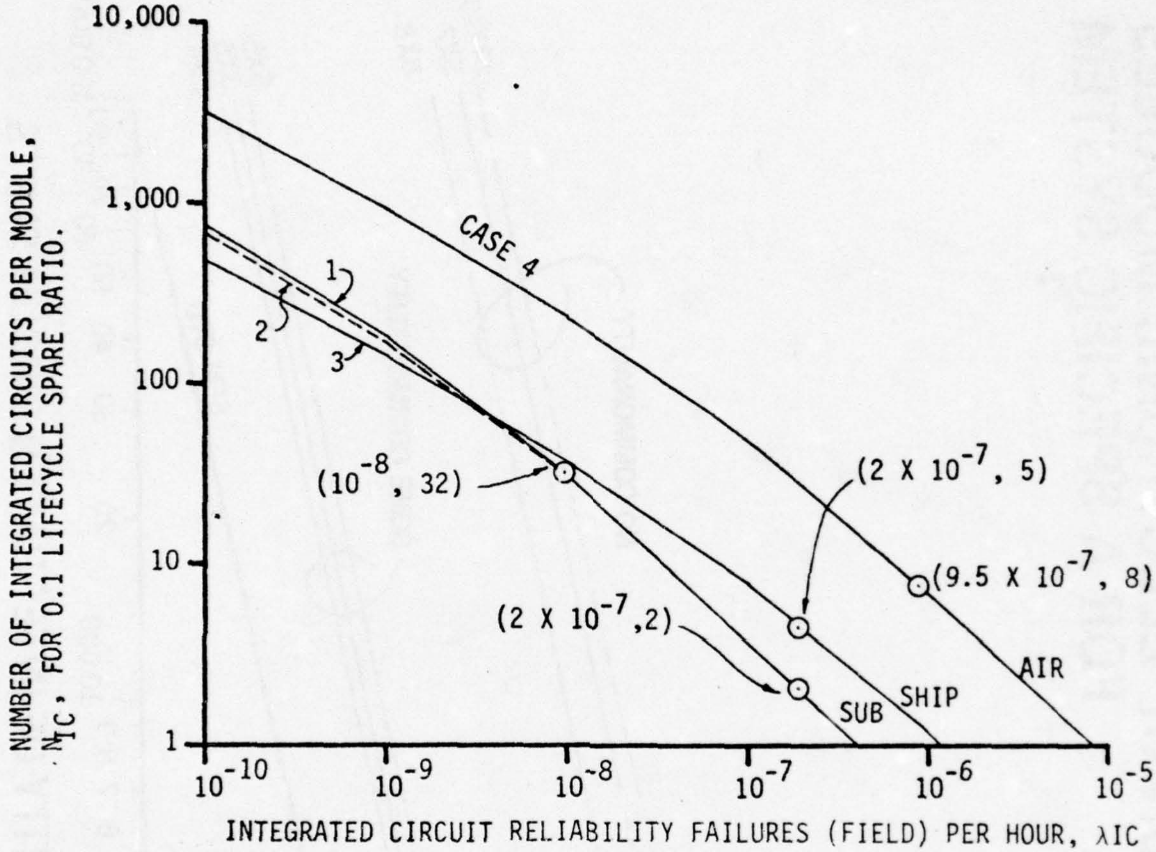


FIGURE 17. NUMBER OF INTEGRATED CIRCUITS PER MODULE FOR 0.98 PROBABILITY OF ADEQUATE SPARES AND 0.1 SPARE RATIO.

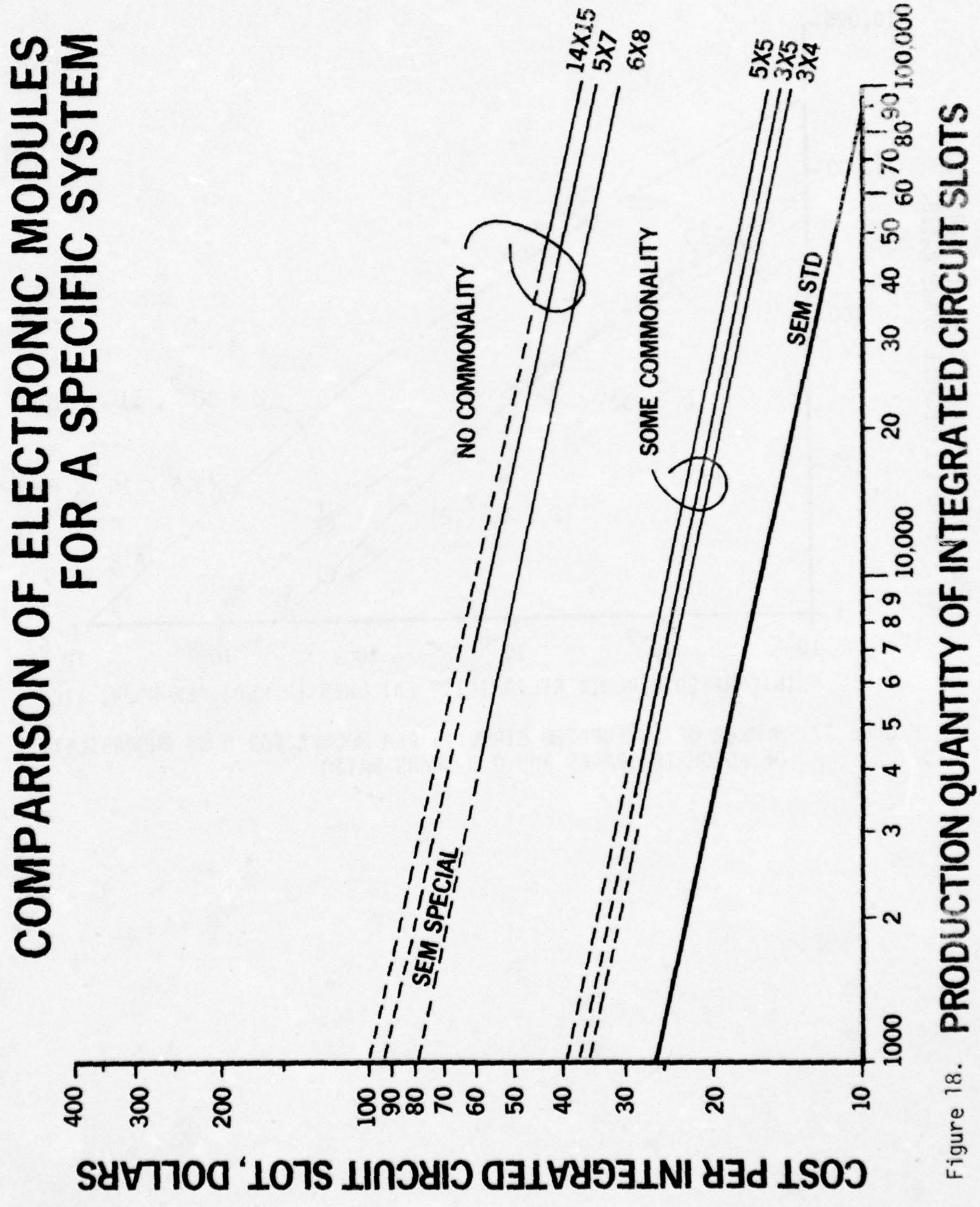

COMPARISON OF ELECTRONIC MODULES
FOR A SPECIFIC SYSTEM
COST PER INTEGRATED CIRCUIT SLOT, DOLLARS
400
300
200
100
90
80
70
60
50
40
30
20
10
PRODUCTION QUANTITY OF INTEGRATED CIRCUIT SLOTS
1000
2
3
4
5
6
7
8
9
10,000
20
30
40
50
60
70
80
90
100,000
NO COMMONALITY
SEM SPECIAL
14X15
5X7
6X8
SOME COMMONALITY
5X5
3X5
3X4
SEM STD

Figure 18.

G. USE ENVIRONMENT

The objective of the subtask entitled Use Environment is to determine the environmental specifications, the mounting system, and the cooling methods that should be considered (and made available) for the design of a proposed Standard Electronic Module. This was accomplished through a program of interviews with personnel located at various installations who prepare avionic specifications, who design avionic equipments, and who rework avionics equipment after a period of in-service usage. Interviews were also held with personnel who design the Environmental Control Systems (ECS) for high performance aircraft and who design missile electronics.

To summarize the results of the subtask, the following trends in avionic design were identified:

1. Avionic equipments are hard mounted to the airframe.

2. Avionic equipments are cooled by:

   a. Air

   b. liquid only, if required.

3. Avionic equipments are cooled from the edge of the component mounting card.

4. Avionic equipments are cooled by less humid air then previously available because of the advances made in the ECS.

5. Avionic equipments are designed to fit particular spaces rather than a particular box configuration (i.e., Austin Trumbull Radio (ATR) racking configuration).

6. Concern for low Mean Time Between Failure (MTBF) of avionics equipments and the need for improvement has become evident.

7. Use of lower temperature air for avionic cooling to increase the MTBF has become a practice.

8. Recognition that a portion of the low MTBF of avionics is attributable to ground support equipment problems.

Failure of present electronics in avionics equipment due to use environment may be attributed to the following:

1. Temperature - To satisfy the requirement for more electronics on high performance aircraft, avionic designers have increased the compactness of the equipment which has resulted in higher component temperatures. Air Force field failure analysis indicates temperature has been the factor most likely to cause failure in avionics. The high performance aircraft is not the only user of electronics which has been plagued with temperature failure. Reports available on Navy surface ships indicate excessive temperature has been the major cause of electronic equipment failure. In the case of Naval surface ships the excessive temperature has not normally been due to equipment compactness but to poor installation and/or maintenance. Whatever the cause, temperature, in excess of that allowable for high MTBF, has been deemed the chief cause of field failure of electronic equipment.

2. Vibration & Humidity - Vibration and humidity form a second group which has been considered to be a large contributing factor in overall field failure of electronic equipment. The Air Force indicated that 36% of the field failures reported have been determined to be due to vibration or humidity. The visit to the Naval Air Rework Facility (NARF) was a point in fact because the A-6 was being retrofitted with a different type of vibration isolator, and the F-14 was being provided drip loops in the equipment inter-connecting cables. Many field failures of electronic equipment could have been prevented if sound design principles had been applied to vibration and humidity problems.

3. Shock - The Use Environment subtask indicated that the time of application of the shock loading on equipment in field service was quite different from that defined by the general equipment specification. Further, the location of electronic equipment in the aircraft structure could change considerably the loading imposed upon the equipment. A revision of the general equipment specification for electronic equipment which would detail shock loading time more closely to that found from field experience could reduce field failure due to shock by requiring more realistic equipment mechanical designs.

Key environmental specifications for air, ship, ground, and missile equipment were tabulated and are listed in Appendix C. These data were taken from general equipment specifications and specifications for specific equipment.

These reference data were accumulated with the objective of establishing a common module environmental specification to satisfy the majority of applications.

A module is exposed to a somewhat different environment than the equipment of which it is a part. Translation factors between equipment requirements and module requirements were developed by a team of test and design engineers. The translation factors are intended to represent what can be achieved practically with good engineering practice.

Module environmental shock and vibration requirements derived from the reference data and translation factors are listed in Table 16 in the form of equipment requirements and the translation factor needed to convert equipment requirements to module requirements.

Shipboard shock and airborne vibration requirements include all but the most extreme environments which are not too common with the exception of large missile launch vibration requirements.

Proposed module environmental specification requirements covering the majority of applications are listed in Table 17.

Table 16

MODULE REQUIREMENTS

VEHICLE CLASS	ELECTRONIC EQUIPMENT REQUIREMENT		TRANSLATION FACTOR	
	SHOCK	VIBRATION	SHOCK	VIBRATION
SHIPBOARD GROUND BASED SUBMARINE	(901) 400-600g (HAMMER) <1 ms 50g 11 ms 1/2 SINE 100g 6 ms SAWTOOTH Ⓐ	5-55 Hz (.06" DA-.02" DA)	1:1 Ⓐ	3:1 5:1
MOBILE VAN GROUND S/E	LESS SEVERE THAN ABOVE	5-200 Hz (LOW AMPLITUDE)	SEE ABOVE	SEE ABOVE UP TO 200 Hz
AVIONICS-HP AVIONICS HELICOPTERS	(5400) 15g 11 ms OR > ACOUSTICAL	5-2000 Hz (.10" DA-20g) RANDOM Ⓑ	SEE ABOVE	5:1 TO 2000 Hz Ⓑ
MANPACK	LESS SEVERE MAINLY TRANSPORTATION	LESS SEVERE MAINLY TRANSPORTATION	SEE ABOVE	SEE ABOVE
MISSILE/SATELLITE	SEE SHIPBOARD PYROTECHNIC	5-3000 (.20" DA-50g) RANDOM ($1.5g^2$/Hz)	SEE ABOVE PYROTECHNIC	5:1 10:1 TO 3000 Hz

Ⓐ MODULE SPECIFICATION FOR SHOCK TESTING
Ⓑ MODULE SPECIFICATION FOR VIBRATION TESTING

TABLE 17

MODULE ENVIRONMENTAL REQUIREMENTS

I. Shock: MIL-STD-810C Method 516.2 Procedure IV, high intensity test flight vehicle equipment(figure 516.2-1).

II. Vibration: MIL-STD-810C Method 514.2 Procedures I and IA modified as follows:

1) Curve H of figure 514.2-2 (page 514.2-22 of MIL-STD-810C) shall be followed except the 10g specification shall be increased to 50g.

2) The max displacement (inches - Double amplitude) shall be increased from 0.10 inches to 0.50 inches for curve H figure 514.2-2.

3) Resonant dwells Method 514.2 Section 4.5.1.2 shall be eliminated.

4) For the random vibration test the random vibration envelope shall be in accordance with figure 514.2-2A Random Vibration Envelope with a W_o of 1.5 G^2/Hz for functional and 2.0 G^2/Hz for endurance tests.

III. Temperature: (operational) The max. semiconductor junction temperature shall be 125°C with a max. module interface temperature of 85°C. The module shall also operate at -54°C.

Temperature: (storage) -62 to +95^{o}C

TABLE 17 (Cont.)

IV. Altitude - Sea level to 70,000 feet

V. Humidity - MIL-STD-810C Method 507.1 Procedure 1 with the exception that the maximum humidity be increased to 100%.

VI. Fungus - MIL-STD-810C Method 508.1 - Procedure 1.

VII. Explosive Proofing - MIL-STD-810C Method 511.1 Procedure 1.

VIII. Corrosion Resistance - MIL-STD-810C Method 509.1 Procedure 1.

H. TRADE-OFF CRITERIA

1. DATA REDUCTION

The objective of data reduction is to manipulate raw data into a meaningful form that can be used for decision making. The flow path used to reduce the diverse inputs into one meaningful statement is given in Figure 19. The process starts with a parallel effort, the definition of criteria and the gathering of data. This is a parallel effort since the criteria requirements must be tempered by determining what data is available. After the list of criteria and their definitions have been established, they are validated to confirm that they actually measure the desired parameter. With numerical data, this amounts to making sample calculations and observing the results. With subjective data validation is often done by having the criteria reviewed by a panel of experts and sample evaluations conducted on known "benchmark" data. This group also establishes boundary conditions which delimit areas of physical, technical or cost parameters that are desirable.

These criteria are now prioritized in order of importance by using a "forced paired comparison" technique. This technique forces the rater to make a judgment of the relative importance of each combinational pair of criteria, one pair at a time. While the total number of combinational pairs may be quite high, at any one time the rater need only be concerned with the relative evaluation of two items. The result is a score which is the number of times that a criterion was judged to be the more important. The process also develops a raw "weight" or definition of how much more important one criterion is over another. These weights may be modified by the judges for particular applications and validated in the same manner as the criteria.

After the criteria have been prioritized and weights established, the modules are evaluated with respect to the criteria. Taking each criterion, one at a time, the module data are examined and the modules are prioritized by use of a forced paired comparison for that one criterion. By repeating the process for all of the criteria, each module is completely evaluated and a composite module score can be developed. The "best" module

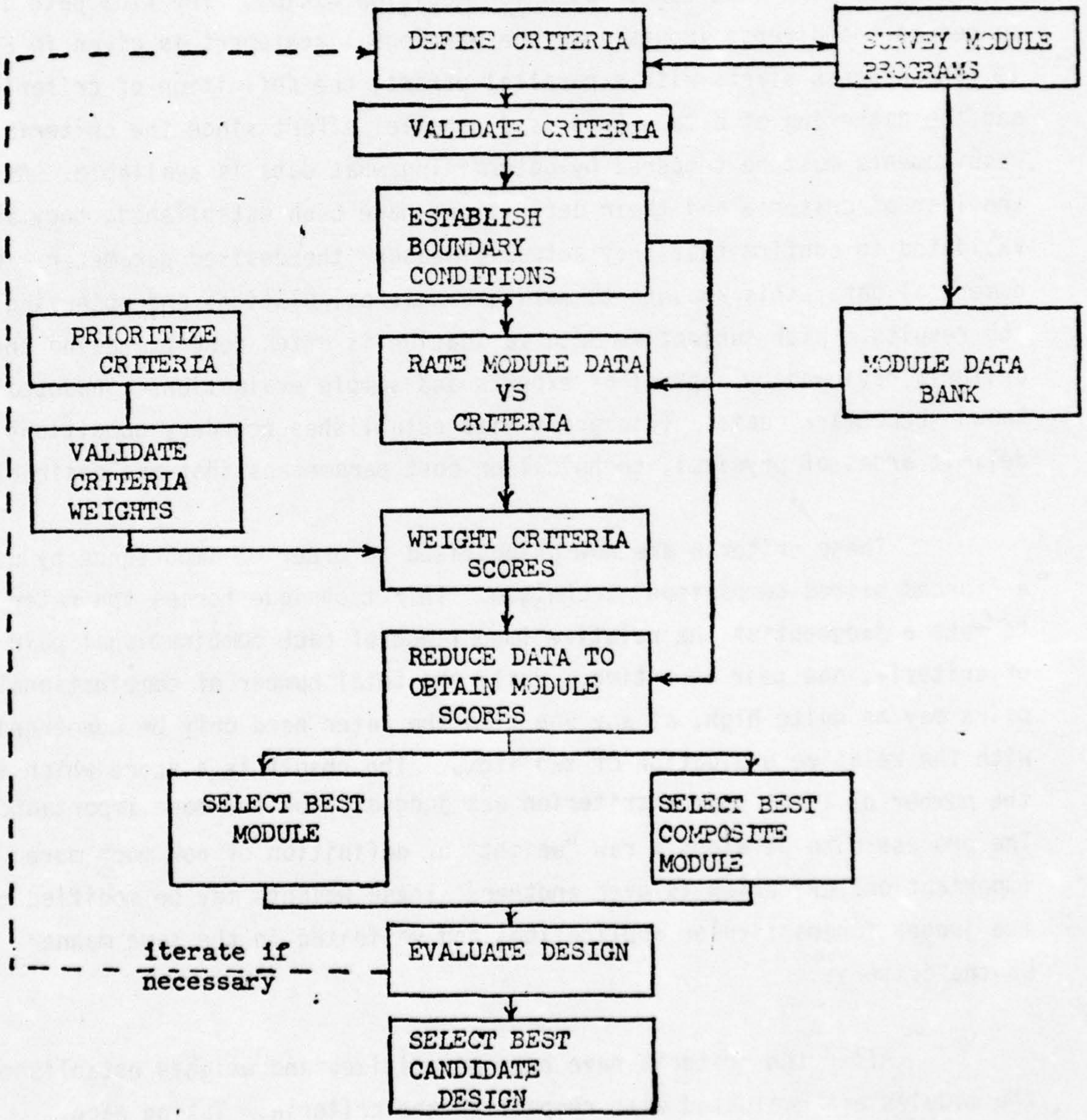


Figure 19. Program Flow Chart

can be selected or a composite module can be developed utilizing the best features from several modules. An iterative loop is included in the flow path to accommodate problems that might arise such as new technology inputs, a process difficulty in a new composite design, etc.

2. CRITERIA

In order to insure that all of the raters used the same rules with which to rate, each of the criterion was defined as listed in Appendix D. The order of this list is randomized and is the same order that was presented to the rating committee. Figure 20 is the prioritized order of the criteria, the most important criterion appearing at the top. Appearing next to the criteria are the raw weights associated with that criterion. These are a measure of the relative importance of the criterion, indicating ties, etc. These raw weights give a weighting spread from the most important criterion to the least important equal to the number of criteria, or in this case, 27:1. The rating committee subsequently modified the spread from 27:1 to 4:1. This modification retains the information on ties, etc. but limits the weight or importance of the top-rated criterion to four times that of the least important criterion.

4:1 WEIGHT	RAW WEIGHT	SCORE	CRITERIA ORDER
.0949	.0740	26	Functional Flexibility
.0921	.0712	25	Number of Pins
.0864	.0655	23	Reliability/IC
.0864	.0655	23	Watts/Volume
.0807	.0598	21	IC Operating Cost/Hour
.0778	.0569	20	SEM Compatibility
.0749	.0541	19	Applications Flexibility - Mechanical
.0749	.0541	19	^{o}C/Watt/Board Area
.0749	.0541	19	Technology Compatibility
.0722	.0513	18	Environmental Flexibility
.0636	.0427	18	Weight/IC
.0608	.0399	14	Reliability - Mechanical
.0579	.0370	13	Quality
.0551	.0342	12	Thermal Resistance - Internal
.0551	.0342	12	Volume/IC
.0522	.0313	11	Producibility
.0494	.0285	10	Number of Pins/In^2
.0494	.0285	10	Cost of Module
.0465	.0256	9	Cost/IC
.0437	.0228	8	Testability
.0437	.0228	8	System Maintainability
.0380	.0171	6	General Mechanical
.0323	.0114	4	Aspect Ratio
.0266	.0057	2	Connector Flexibility
.0266	.0057	2	Incremental Growth
.0237	.0028	1	Extraction/Insertion Force
.0237	.0028	1	Pin Spacing

Figure 20. Prioritized Criteria Order

V. CONCEPTUAL MODULE DEFINITION

A. As a result of the various parametric and non-parametric module packaging studies performed, a number of candidate conceptual modules were identified by NAFI and NWSC, Crane. Five differing conceptual modules were presented by NAFI/NWSC at the 7 April 1976 SEM R&D technical review meeting at NAFI. An additional candidate module was considered subsequent to that review. Presented herein are the physical parameters of these modules, the rationale for their selection, and some thoughts regarding their continued consideration as a candidate conceptual module or module family.

The physical parameters (module size, active circuit board area, and I/O pin count) and type of thermal interface for the initial five conceptual modules are provided in Table 18. To provide an insight into why these particular module concepts were selected as candidate new SEM modules and their applicability to the results of the packaging studies, rationale is provided for the selection of each of the modules.

<u>CONCEPTUAL MODULE #1</u>: The primary consideration for selection of this module was sizing the active circuit board area and I/O pin count to the results of the function background task. The function background task concluded that a printed wiring board with 13.8 to 15.7 square inches of active component mounting area will allow packaging 95% of the 83 function data base, with an optimum active component mounting area of 12.5 to 14.3 square inches (based on the functional flexibility analysis). Additionally, the function background task concluded that 102 I/O pins will allow packaging 95% of the 83 function data base, with an optimum pin count of 80 (based on the functional flexibility analysis).

Therefore, a module with 13.8 square inches of active component mounting area and 100 I/O pins provided a near ideal fit with the function background task results. Other considerations included sizing the height in order to accomodate two 22 pin or one 40 pin DIP vertically,

CANDIDATE CONCEPTUAL MODULE	OVERALL MODULE DIMENSIONS (IN)		ACTIVE CIRCUIT BOARD DIMENSIONS (IN) & AREA (IN^2)			PIN COUNT (.1 IN. CENTERS)	THERMAL INTERFACE
	HEIGHT (1)	SPAN (2)	HEIGHT	SPAN	AREA		
#1	3.2	5.44	2.6	5.3	13.8	100	.29 In. Side Ribs (Conduction)
#2	3.2	8.44	2.6	8.3	21.6	160	.29 In. Side Ribs (Conduction
#3 (XN-1 Package)	4.0	4.0	3.0	4.0	24.0 (3)	304 (6)	Center Heat Exchanger (Hollow Card)
#4 (Improved SEM)							.09 In. Side Ribs (Conduction)
1A	1.89	2.44	1.3	2.3	2.99	40	
2A	1.89	5.44	1.3	5.3	6.89	100	
2B	1.89	5.44	1.3	5.3(X2)	13.78	200	
#5 (Air Force Candidate Concept: Mother, Daughter, Baby Board)	6.2 (4)	9 (4)	(5)	(5)	(5)		Conduction

Table 18. Conceptual Module Physical Parameters

Notes:
(1) Measured from Top of Back Panel Interconnect Board to Top of Module.
(2) Measured as Distance Between Side Rails (Card Cage).
(3) Assume P.C. Board on Both Sides of Module (Flat Pacs Only).
(4) Dimensions of Daughter Board.
(5) Varies Dependent Upon Choice of Baby SEM Size.
(6) Zero-Insertion Force Connector, All Others are Blade and Tuning Fork Type.

while restraining the height such that the modules could be utilized back-to-back within the height of the ARINC 404A ATR enclosure (modules insert from top and from bottom of ATR enclosure). The module span was thereby able to be sized to be compatible with the existing SEM 2A module span. ATR enclosure compatibility includes the 3/8, 1/2, 3/4, and full ATR size. (Note: See Section IV.D. for discussion of conceptual module compatibility with various ATR enclosures.) Incremental growth was established by providing for a one-half span module (3.2 x 2.4 inch) with 40 I/O pins to accommodate less complex functions, and a double pitch module (3.2 x 5.4 x 0.6 inches) with 200 pins to accommodate more complex functions.

CONCEPTUAL MODULE #2: The primary criteria used in selection of this conceptual module was sizing the span to a full ATR enclosure. The active component mounting area and I/O pin count exceed significantly the requirements derived from the function background task, and are therefore considered compatible. The module height selection rationale is identical to that of conceptual module #1. Incremental growth was established by providing for a one-half span module (3.2 x 3.4 inches) with 60 I/O pins to accommodate smaller level functions, and a double pitch module (3.2 x 8.4 x 0.6 inches) with 320 pins to accommodate more complex functions.

CONCEPTUAL MODULE #3 (XN-1 PACKAGE): The XN-1 module package concept originated from the All Applications Digital Computer (AADC) program. The concept originated as a technique for packaging the 3-inch whole LSI wafer, thereby requiring a zero-insertion force (ZIF) connector to provide the required quantity of I/O pins. The hollow card approach with a center heat exchanger was chosen in order to be able to dissipate the heat associated with the whole wafer technology. The module concept selected as a candidate SEM module was the flat-pack configuration which allows for mounting of a circuit board on both sides of the center heat exchanger. This configuration will not easily accommodate DIPs without the DIP leads protruding through the heat exchanger. Since the ability of a module to accommodate DIPs is essential, a practical DIP configuration needs to be developed if this concept is to be pursued as a new SEM module.

As with concept #2, the module active component mounting area and I/O pin count far exceed the requirements derived from the function background task, and are therefore considered compatible. The module is limited to ½ ATR enclosure compatibility. The primary criteria for inclusion of the XN-1 package as a candidate module were its tremendous I/O pin capability and the investment to date in this packaging concept.

CONCEPTUAL MODULE #4 (Improved SEM): Improved SEM is defined as the existing SEM (1A, 2A, and 2B) overall module dimensions with the circuit board extended through the fin area to the top of the module, the side guides (ribs) extended to the full height of the module and increased in span by .09 inches (each side) and the 2A 80-pin connector expanded to 100 pins by filling in the center space. In a similar manner, the 2B module connector is extended from a capability of 160 to 200 pins.

The primary rationale for including the improved SEM as a candidate conceptual module was to capitalize on the investment in this program by maintaining total compatibility with the existing SEM module family. In addition, its selection is well supported when comparing the improved SEM physical parameters with the outputs of the packaging studies. The improved 2B module is compatible with the function analysis results in both active component mounting area and I/O pin count. Also, the improved 2A module provides sufficient active component mounting area to accommodate approximately 60 percent of the 83 function data base. Improved SEM provides compatibility with all ATR enclosure sizes investigated (1/4, 3/8, 1/2, 3/4, and full). Incremental growth is provided in both module span and pitch (thickness). In addition, improved SEM more closely fits the results of the cost bounds task (module cost tradeoff analysis) than any other conceptual module selected.

CONCEPTUAL MODULE #5 (Air Force Candidate Concept): This concept, proposed to the Air Force by Westinghouse, consists of a mother, daughter, baby board approach where the baby board is considered the SEM. The daughter board (6.2 x 9 inches) is sized to a full ATR enclosure. The SEMs (baby boards) can be of various physical sizes dependent upon the

circuit function being implemented. Interconnection of the SEMs to the daughter board can be accomplished by either direct soldering or by pin and socket connectors.

This concept was included as a candidate conceptual module because of its potential functional flexibility and potential high density, light weight packaging approach. The analysis approach was merely to monitor the Air Force progress and analysis of this concept.

B. Section VI. of this report provides a summary of the results obtained from application of the 27 module trade-off criteria (See Section IV.H.) to the conceptual modules, except for concept #5 due to the lack of sufficient technical data to adequately assess this concept. In addition to this analysis, the conceptual modules were evaluated from an engineering judgment viewpoint to assess the worthwhileness of continued consideration as a candidate conceptual module or module family. This judgment was based on past engineering experience and that gained throughout this module packaging effort. These judgments are as follows:

<u>CONCEPTUAL MODULE #2</u>: The aspect ratio $\left(\frac{H}{S}\right)$ of this module is less than ideal from both a mechanical integrity and a thermal viewpoint. Potential exists for undesirable vibration characteristics. Inadequate thermal characteristics may result due to the large thermal resistance for components mounted near the center of the module. The most feasible approach to resolve the potential problem areas would be to size the height of this module to the ATR enclosure, if a need for a module of this physical size can be established. In conclusion, concept #2 as it currently exists will not be given further consideration as a candidate SEM module.

<u>CONCEPTUAL MODULE #3 (XN-1 PACKAGE)</u>: The feasibility of this concept depends upon the availability of a reliable, producible ZIF connector and the development of a DIP module configuration. Based on testing of a ZIF connector configuration at NAFI and a survey of current industry

connector manufacturers, it is judged that the ZIF type connector is not ready for military module usage at this time. This judgment is based on the lack of a dependable and reliable mechanical configuration and the lack of established reliability data for ZIF connectors. In addition, development of a practical and thermally adequate module configuration for DIPs presents a challenging engineering problem. It is intended that the test and evaluation of an improved ZIF connector in a mechanically stable higher level package, to be performed at NAFI in early FY 1977, will provide the data to determine whether the XN-1 package concept should be further pursued.

CONCEPTUAL MODULE #4 (Improved SEM): It is concluded that the improved SEM development should be continued, and a determination made whether an additional SEM module or module family is required.

CONCEPTUAL MODULE #5 (Air Force Candidate Concept): The proposed manner in which the SEMs (baby boards) are to be attached to the daughter board raises concern in the following areas:

- Thermal interface (and resulting thermal efficiency)
- Maintainability
- Testability
- Handling (damage due to lack of protective surfaces)

These concerns are shared by the Air Force sponsoring activity who are not considering this approach for their near term standard avionics module. The conclusion is that this concept be removed from the candidate conceptual SEM module listing.

C. Subsequent to the establishment of the five conceptual modules, an industry source proposed a distinct module packaging approach for avionics. The approach consists of a package measuring approximately 0.6 x 1.25 x 1.0 inches with the components mounted cordwood style between two printed circuit boards. The IC capability of this module is approximately

equivalent to an existing SEM 1A module. The module contains a connector for mating to a daughter board and is mechanically secured to a thermal plane on the board. The daughter board can contain 21 cordwood modules, and is 1/2 ATR compatible. Functional compatibility with existing SEM is proposed.

An attempt was made to evaluate the module on the basis of the 27 trade-off criteria, but sufficient technical data were not available to perform a valid analysis. A significant volume and weight advantage over existing SEM is claimed, but the proported advantages were not validated as of the preparation of this report. Concerns exist in the areas of producibility, thermal adequacy, and reliability. A preliminary cost analysis was performed at NAFI which indicated approximately 40 percent higher production cost than a functionally equivalent SEM module in quantities of 100 to 500. The industry source is planning to invest a low level of IR&D funding to investigate producibility and thermal efficiency.

The inherent difficulties of a cordwood packaging concept suggest that it not be considered for a standard module concept. There are likely some unique applications where the use of this concept is well suited, but it is believed that these are limited. The results of the industry IR&D efforts will be monitored.

VI. MODULE TRADE-OFF RESULTS

A. BACKGROUND MODULES

The SEM module evaluation effort examined data from 13 existing standard module programs: SEM 1A, SEM 2A, SAM D, AEGIS, MK 86, MK 5, QED, ML 1, F 14, XN 1, 4π, F 15 and ARPS. In addition to reducing the data for a 4:1 weight as determined by the evaluation committee, weights were run for a 1:1, 2:1, 8:1, 16:1 and 27:1 ratio between the most and least important criterion. These results are given in Figure 21. It is apparent that the results are not very sensitive to criteria weights as the top three candidate modules and the bottom three modules do not change as the weights are varied from 1:1 to 27:1. The only changes are a modest shuffling of the middle 7 modules.

B. CONCEPTUAL MODULES

After evaluating the reduced data on the 13 background modules, five paper-design conceptual modules were developed and evaluated along with the original 13 background modules. These conceptual designs were C#1, basically a SEM 2A module that is 3" high or 5.6 x 3 inches; C#2, a larger module, approximately 3 x 9 inches that will efficiently fit a full ATR case; IMP 1A, an improved SEM 1A module that allows the circuitry to extend up into the present fin area; IMP 2A, an improved SEM 2A module that allows the circuitry to extend up into the present fin area; and IMP 2B, an improved SEM 2B module that allows the circuitry to extend up into the present fin area. Again the analysis was run for a variety of different criteria weights. The results are shown in Figure 22 and again the results did not appear to be sensitive to weighting.

The lack of any modules specifically designed for aircraft applications in the top third of the prioritized list led to questioning the basic validity of the original criteria with the supposition that they might produce a bias against "aircraft" modules. In an effort to investigate any potential bias of this type, another run was made not using the joint criteria developed by the entire rating committee but rather the criteria developed by representatives from WPAFB. The prioritized module list

SUMMARY					
WEIGHT 1:1	WEIGHT 2:1	WEIGHT 4:1	WEIGHT 8:1	WEIGHT 16:1	WEIGHT 27:1
SEM 1A	SEM 1A	SEM 1A	SEM 1A	SEM 1A	SEM 1A
SEM 2A	SEM 2A	SAM D	SAM D	SAM D	SAM D
SAM D	SAM D	SEM 2A	SEM 2A	SEM 2A	SEM 2A
AEGIS	QED	AEGIS	MK 86	MK 86	MK 86
MK 86	AEGIS	QED	AEGIS	AEGIS	AEGIS
QED	MK 86	MK 86	QED	ML 1	QED
MK 5	ML 1	ML 1	ML 1	QED	ML 1
ML 1	MK 5	MK 5	MK 5	MK 5	F 15
4 π	4 π	4 π	4 π	4 π	MK 5
F 15	F 15	F 15	F 15	F 15	4 π
F 14	F 14	F 14	F 14	F 14	F 15
XN 1	XN 1	XN 1	XN 1	XN 1	XN 1
ARPS	ARPS	ARPS	ARPS	ARPS	ARPS

Figure 21. Thirteen Existing Modules Candidate Order

Figure 22. Module Trade-Off Order Including Conceptual Designs

WEIGHT 1:1	WEIGHT 2:1	WEIGHT 4:1	WEIGHT 8:1	WEIGHT 16:1	WEIGHT 27:1
IMP 1A	IMP 1A	IMP 1A	IMP 1A	IMP 1A	IMP 1A
SEM 1A	SEM 1A	SEM 1A	SEM 1A	SEM 1A	SEM 1A
IMP 2A	IMP 2A	IMP 2A	IMP 2A	IMP 2A	IMP 2A
C#1	C# 1	C# 1	C# 1	C# 1	C# 1
SEM 2A	SEM 2A	SEM 2A	SEM 2A	SEM 2A	SEM 2A
SAM D	SAM D	SAM D	MK 86	MK 86	MK 86
AEGIS	AEGIS	MK 86	SAM D	SAM D	SAM D
MK 86	MK 86	AEGIS	AEGIS	AEGIS	AEGIS
IMP 2B	IMP 2B	IMP 2B	ML 1	ML 1	ML 1
QED	QED	ML 1	IMP 2B	QED	QED
MK 5	ML 1	QED	QED	IMP 2B	IMP 2B
C# 2	MK 5	C# 2	MK 5	MK 5	MK 5
ML 1	C# 2	MK 5	C# 2	C# 2	C# 2
F 14	F 14	F 14	F 14	F 14	F 14
XN 1	XN 1	XN 1	XN 1	XN 1	XN 1
4 π	4 π	4 π	4 π	4 π	4 π
F 15	F 51	F 15	F 15	F 15	F 15
ARPS	ARPS	ARPS	APRS	ARPS	ARPS

based on a 4:1 weight ratio is given in Figure 23. Noting that there was not a significant change in the order of the modules in this list, another run was made using an "aircraft criteria". The "aircraft criteria" puts VOL/IC, WEIGHT/IC, RELIABILITY/IC, NUMBER OF PINS, and COST/IC at the top of the prioritized criteria list with the top five weights and the remaining 22 criteria given the remaining 22 weights in their proper descending order. These results are given in the second column of Figure 23 and again little change is noticed in the module order. A slightly more radical approach was taken next which used <u>only</u> the five "aircraft criteria" with a 1:1 weight. A final approach was to use only two criteria, WEIGHT and VOLUME, the two most often cited criteria as being important in aircraft applications. The results for these two runs are also given in Figure 23 and in both cases the results do not differ greatly from the original runs using the joint criteria developed by the SEM rating committee.

WPAFB CRITERIA WEIGHT 4:1	"AIRCRAFT CRITERIA" WEIGHT 4:1	AIRCRAFT CRITERIA ONLY	WEIGHT & VOL ONLY
IMP 1A	IMP 1A	C# 1	C# 2
SEM 1A	SEM 1A	C# 2	C# 1
IMP 2A	C# 1	MK 86	IMP 2A
C# 1	IMP 2A	IMP 2A	IMP 2B
MK 86	SEM 2A	AEGIS	IMP 1A
AEGIS	MK 86	IMP 2B	SEM 2A
SEM 2A	AEGIS	ML 1	ML 1
SAM D	SAM D	IMP 1A	QED
QED	IMP 2B	QED	MK 86
IMP 2B	QED	SEM 2A	MK 5
ML 1	ML 1	SAM D	F 14
MK 5	C# 2	F 14	AEGIS
C# 2	MK 5	XN 1	SEM 1A
F 14	F 14	MK 5	4 π
XN 1	XN 1	SEM 1A	SAM D
4 π	4 π	ARPS	F 15
F 15	F 15	4 π	XN 1
ARPS	ARPS	F 15	ARPS

Figure 23. Module Trade-Off Order for Special Criteria

VII. NAVY/INDUSTRY REVIEW COMMENTS

A. As the opportunity arose, the module packaging studies and resulting conceptual modules were presented to Navy and industry representatives for their reaction and comment. While it is recognized that a formal Navy/industry review is planned during the ensuing months, the comments provided to date provide an interesting insight to the module selection task and are worthy of reviewing. The comments received are not quoted verbatim, but it is believed that the trend of thought is substantially as stated herein. Since on each occasion the audience was not aware that the comments might be published, anonymity will be provided to the individual and his activity/company.

1. (Existing SEM user) - The packaging problem presented when attempting to mix existing SEM and a new module of a different height within the same higher level package is significant. Would question wide-spread mixing of old and new modules within the same box. For a new module, large DIP (i.e. 40 pins or greater) compatibility is required.

2. (Non-SEM user) - Concern for compatibility with existing SEM should be a prime consideration in the selection of a new module form factor. The marginal gain in circuit board area for conceptual module #1 over "improved SEM" is certainly not worth the loss in SEM compatibility. The "improved SEM" 2B module would clearly be a superior choice over conceptual module #1. The maturity of multi-layer boards and interboard connection techniques support the choice of the "improved SEM" 2B over concept #1.

3. (Non-SEM user, but familiar with program) - Conceptual module #1 appears to have approximately the required circuit board area. Do not believe that "improved SEM" has sufficient circuit board area, but it is an interesting approach and should be considered.

4. (Existing SEM user) - Cannot imagine many, if any, digital functions having intersystem commonality that would not fit on an "improved

SEM" 2A module. A 100 pin I/O connector may be required, but believe that 80 pins would satisfy most all requirements. Minimum compatibility of any new SEM module with existing SEM should be the blade and tuning fork connector on 0.1 inch centers.

5. (Existing SEM user) - Technology is driving the required module circuit board area smaller. However, higher level functions are requiring additional I/O pins. The zero insertion force connector may be required to satisfy future module function requirements.

6. (Existing SEM user) -

a. Cannot imagine any electronic function having potential intersystem commonality that would exceed a module I/O pin count of 120. All NELC QED functions can be implemented with 100 pins, and the "improved SEM" 2A module would have sufficient board area for the majority of these. The balance would fit easily on an "improved SEM" 2B module. There are only a few large function modules that can be identified as having potential intersystem commonality. These will fit on the "improved SEM" 2A module. Estimate that an average system will use 12 components per 2A module.

b. Expect to see great usage of 28 and 40 pin DIPs. The "improved SEM" height will be acceptable, since not many, if any, functions will require more than one 40 pin DIP.

c. Conceptual module #1 would be a good industry mechanical standard, but will yield many unique modules since designers will tend to cram as much circuitry as possible on the module. With clever system partitioning and technology choice, the "improved SEM" module will provide a system design of less volume than would concept #1 because of the ever-present need for unit logic which will more efficiently fit on an "improved SEM" 1A module.

B. Additional module packaging comments were obtained during this same time period from individuals not exposed to the SEM packaging studies and conceptual modules. These are summarized as follows.

1. For data processing functionality, a module must be able to accomodate at least 140 ICs. Recommend a 6" x 9" module with 200 I/O pins and able to accomodate 140 DIPs or 160 flat packs.

2. For commercial electronic systems, the small versus large module is controversial from a life cycle cost viewpoint. A large card subsystem presents a logistic support problem in the commercial environment.

3. Industry representative reporting on why they chose a small card (1" x 5") unit logic approach for design of a commercial computer application:

a. Simple daughter board.
b. Daughter board design independent.
c. One-pass computer aided design (CAD) system.
d. Flexible entry to mother board.
e. Overall system cost.

4. Must change more than simply achieving higher density packaging to fit needed electronics into advanced missiles. Hybrids appear to be a more likely solution than LSI which cannot do everything.

5. Memories represent the major hardware packaging cost of aircraft electronics and should be the packaging forcing function.

VIII. REFERENCES

A. Air Force/Industry Standard Electronic Module Workshops, Executive Summary, February 1976.

B. Advanced Standard Electronic Module (SEM) Packaging Trade-Off Study, IBM Federal Systems Division, of 1 November 1975.

C. Function and Configuration Analysis, Draft Report, Hughes Aircraft Co. Contract No. F33615-75-C-1270, Project 6096, Item A003, 1975.

D. Modular Packaging Approaches, Interim Report, Westinghouse Electric Corporation, Contract No. F33615-75-C-1269, of 30 December 1975.

E. I. E. Sutherland and D. Oestreicher, "How Big Should a Printed Circuit Board Be?", IEEE Trans on Computers, May 1973.

F. A. Mennone and R. L. Russo, "An Example Computer Logic Graph and Its Partitions and Mappings", IEEE Trans on Computers, November 1974.

G. ARINC Specification 404A "Air Transport Equipment Cases and Racking".

APPENDIX A

TECHNOLOGY DATA

Table 1. Component Description

PACKAGE*		REF	LEN	WID	PLUS	WID+	HT	AREA
(14p - 1/4" x 1/4")	01	1	0.326	0.280	0.115	0.510	0.085	0.166
(14p - 1/4" x 3/8")	02	1	0.390	0.280	0.115	0.510	0.085	0.199
(14p - 3/16" x 1/4")	03	1	0.326	0.220	0.115	0.450	0.070	0.147
(10p - 1/4" x 1/4")	04	1	0.290	0.240	0.115	0.470	0.085	0.136
(16p - 1/4" x 3/8")	05	1	0.440	0.305	0.115	0.535	0.085	0.235
(24p - 3/8" x 5/8")	06	1	0.640	0.440	0.115	0.670	0.090	0.428
(24p - 3/8" x 1/2")	07	1	0.576	0.395	0.115	0.625	0.090	0.360
(24p - 1/4" x 3/8")	08	1	0.668	0.305	0.115	0.535	0.090	0.357
(40p - MOT 621-01)	09	2	1.040	0.420	0.115	0.650	0.100	0.679
(14p - 1/4" x 3/4")	11	1	0.796	0.320			0.200	0.255
(16p - 1/4" x 7/8")	12	1	0.896	0.320			0.200	0.287
(24p - 1/2" x 1-1/4")	13	1	1.290	0.620			0.225	0.800
(28p - SIGNET)	14	2	1.430	0.620			0.190	0.887
(40p - MOT 699-03)	15	2	2.010	0.625			0.155	1.256
(40p - INTEL CERAMIC)	16	2	2.100	0.700			0.230	1.470
(A1) 8 LEAD TO-5	21	1	DIA 0.370				0.185 to 0.285	0.110
(A2) 10 LEAD TO-5	22	1	DIA 0.370				0.185 to 0.285	0.110
(X) 3 LEAD TO-5	23	1	DIA 0.370				0.260 to 0.360	0.110
(Y) TO-3	24	1	1.550	1.050			0.450 to 0.550	0.388
TO-8	25	2	DIA 0.600				0.175	0.283
1/4W RES RCR07	31	3	0.281	0.098D	0.035	0.356	0.093	0.035
1/8W RES RCR05	32	3	0.160	0.066D	0.035	0.210	0.066	0.014
TUB CAP (TYPICAL)	33	4	0.286	0.135D	0.035		0.135	0.039
CRD 06 CHIP CAP	34	5	0.245	0.270			0.080	0.066
TRIM POT RT-11	35	6	1.280	0.110			0.375	0.141
16p LEADLESS	41	7	0.190+	0.190+	0.020	ADDED TO BOTH LENGTH AND WIDTH	0.036	0.044
18p LEADLESS	42	7	0.260+	0.260+	0.020		0.045	0.078
S24p LEADLESS	43	7	0.345+	0.345+	0.020		0.045	0.133
28p LEADLESS	44	7	0.410+	0.410+	0.020		0.045	0.185
40p LEADLESS	45	7	0.470+	0.470+	0.020		0.045	0.240

Table 1. Component Description (Continued)

PACKAGE*		REF	LEN	WID	PLUS	WID+	HT	AREA
64p LEADLESS	46	7	0.714+	0.714+	0.020		0.045	0.539
1" x 2" HYBRID	51	8	1.000	0.500	0.230	0.730	0.090	0.730
6-22p HYBRID	52	9	0.625	0.500	0.230	0.730	0.120	0.456
30-36p HYBRID	53	9	1.000	0.500	0.230	0.730	0.150	0.730
28-56p HYBRID	54	9	1.490	0.625	0.230	0.855	0.135	1.274
30-64p HYBRID	55	9	1.000	1.000	0.230	1.230	0.210	1.230
19-72p HYBRID	56	9	1.180+	1.180	1.410	0.150	0.150	1.988

*NOTE:
- 01 to 09 - Flatpacks
- 11 to 16 - Dips
- 21 to 25 - Metal Cans
- 31 to 35 - Discrete Components
- 41 to 46 - Leadless Hybrids
- 51 to 56 - Hybrids

REFERENCES:
1. MIL-M-38510A Max. Dim.
2. Industry
3. MIL-R-39008B
4. Industry - Sprague
5. MIL-C-55681
6. MIL-R-27208C
7. 3M Tech Notes
8. Hybrid Ceramic
9. Industry - Isotronics

Table 2. Device Footprint Data

ON 0.1 X 0.1 GRID (MLB)					2 TIMES COMP. AREA EFF = 50%		
PKG	LEN	WID	AREA	EFF %	LEN	WID	AREA
01	0.4	0.6	0.24	69.2	0.56	0.87	0.485
02	0.5	0.6	0.30	66.3	0.67	0.87	0.580
03	0.4	0.5	0.20	73.5	0.56	0.77	0.428
04	0.4	0.5	0.20	68.0	0.50	0.80	0.397
05	0.5	0.6	0.30	78.3	0.75	0.91	0.686
06	0.7	0.8	0.56	76.4	1.09	1.14	1.250
07	0.7	0.7	0.49	73.5	0.98	1.07	1.049
08	0.7	0.7	0.49	72.8	1.14	0.91	1.041
09	1.2	0.8	0.96	70.7	1.78	1.11	1.970
11	0.9	0.4	0.36	70.8	1.36	0.55	0.742
12	1.0	0.4	0.40	71.8	1.53	0.55	0.836
13	1.4	0.8	1.12	71.4	2.20	1.06	2.331
14	1.5	0.8	1.20	73.9	2.44	1.06	2.584
15	2.1	0.8	1.68	74.8	3.43	1.07	3.660
16	2.2	0.9	1.98	74.2	3.58	1.19	4.284
21	0.5	0.5	0.25	43.2	0.523 DIA		0.215
22	0.5	0.5	0.25	43.2	0.523 DIA		0.215
23	0.5	0.5	0.25	43.2	0.523 DIA		0.215
24	1.7	1.2	2.04	19.0	2.65	1.79	4.743
25	0.8	0.8	0.64	44.2	1.20		0.566
31	0.5	0.3	0.15	23.0	0.17	0.61	0.102
32	0.4	0.3	0.12	11.6	0.11	0.36	0.040
33	0.5	0.4	0.20	19.5	0.49	0.23	0.113
34	0.5	0.5	0.25	26.4	0.42	0.46	0.193
35	1.4	0.3	0.42	33.6	2.19	0.19	0.410
41	0.3	0.3	0.09	48.9	0.32	0.32	0.105
42	0.4	0.4	0.16	48.8	0.44	0.44	0.197
43	0.4	0.4	0.16	83.1	0.59	0.59	0.347
44	0.5	0.5	0.25	74.0	0.70	0.70	0.490
45	0.6	0.6	0.36	66.7	0.80	0.80	0.643

Table 2. Device Footprint Data (Continued)

ON 0.1 X 0.1 GRID (MLB)					2 TIMES COMP. AREA EFF = 50%		
PKG	LEN	WID	AREA	EFF %	LEN	WID	AREA
46	0.8	0.8	0.64	84.2	1.22	1.22	1.486
51	1.2	0.9	1.08	67.6	1.71	1.25	1.851
52	0.8	0.9	0.72	63.3	1.07	1.25	1.330
53	1.2	0.9	1.08	67.6	1.71	1.25	2.127
54	1.9	1.0	1.90	67.1	2.54	1.46	3.713
55	1.2	1.4	1.68	73.2	1.71	2.10	3.584
56	1.6	1.6	2.56	77.7	2.41	2.41	5.793

APPENDIX B

COST BOUNDS DEFINITIONS

Definitions

R = Ratio of Life Cycle Spares to System Modules.

N_S = Number of Spares Needed Per System to Satisfy the Sparing Policy (Total at Bases and Depot.)

N_M = Number of Modules Per System.

N_E = Number of Systems Supported by a Particular Spare Stocking Location.

N_T = Number of Module Types Per System.

N_D = Number of Integrated Circuits Per System.

N_{IC} = Number of Integrated Circuits Per Module.

t_L = System Calendar Life, Hours.

t_D = Delay Time in Replacing Spare Module Removed From Stock, Hours.

t_T = Depot Receiving, Shipping, and Testing Time Delay in Cycling Good Returned Modules, Hours.

λ_M = Failure Rate of Module, Failures Per Hour

λ_{IC} = Failure Rate of Integrated Circuit, Failures Per Hour. (Reliable Type Failures Under Normal Operating Conditions. Does Not Include Induced Failures.)

K_L = Ratio of Induced Integrated Circuit Failures Plus Non-Integrated Circuit Module Failures Per Integrated Circuit to Integrated Circuit Reliability Failures.

$$K_L = \frac{\lambda_M - N_{IC}\,\lambda_{IC}}{N_{IC}\,\lambda_{IC}} \quad \text{or} \quad \lambda_M = (1+K_L)N_{IC}\,\lambda_{IC}$$

λ_T = Mean Number of Spares of One Module Type Removed From Stock During Time, t_D.

K_{GB} = Number of Good Modules Returned as Failed For Each Failed Module.

M = Number of Operating Base Locations.

K_{OC} = Ratio of Operating Hours to Calendar Hours.

E_x = Number of Standard Deviations Needed Above Mean For "x" Probability of Adequate Spares of Any One Module Type During Time, t_D. Gaussian Normal Probability is Assumed with Mean Equal to Variance and Equal to λ_T.

$P(s)=(x)^{N_T}$ = Probability of Adequate Spares for System Having N_T Types of Modules during Time, t_D.

N_{EB} = Number of Operating Systems Supported by a Base.

N_{ED} = Number of Operating Systems Supported by a Depot.

N_{ED} = MxN_{EB}, if Only One Depot.

N_{SB} = Number of Spares Stocked at a Base.

N_{SD} = Number of Spares Stocked at a Depot.

t_{DD} = Delay Time in Replacing Spare Module Removed From Base Stock, Hours.

t_{DF} = Delay Time in Replacing Spare Module Removed From Depot Stock, Hours.

λ_{TB} = Mean Number of Spares of One Module Type Removed From Base Stock During Time, t_{DD}.

λ_{TD} = Mean Number of Spares of One Module Type Removed From Depot Stock During Time, t_{DF}.

x = Probability of Adequate Spares of Any One Module Type During Time, t_D.

APPENDIX C

ENVIRONMENTAL SPECIFICATIONS

Table 1

GENERAL SPECIFICATION	MIL-E-4158E (GROUND)		MIL-E-5400 (AIRBORNE)			
Temperature	Operating	Nonoperating	Operating	Nonoperating	Altitude	Opera[illegible]
OUTDOOR:						
Cold Weather	-54°(-65°F) to +52°C(+125°F)[2]	-	-	-	-	
Temperature	-40°(-40°F) to +52°C(+125°F)[2]	-	-	-	-	
Desert/Tropical[1]	0°(+32°F) to +71°C(+160°F)[2]	-	-	-	-	
INDOOR:						
All Areas	-	0°(+32°F) to +52°C(+125°F)[2]	-	-	-	
STORAGE:						
All Areas	-	-62°(-80°F) to +71°C(+160°F)[2]	-	-	-	
TEMPERATURE RANGE:						
Class 1	-	-	-54°C to 55°C(-65° to +131°F)[3] continuous sea level (30.0 in. Hg) operation	-62° to +85°C(-80° to +185°F) (Extremes/shock)	50,000 feet (3.4 in. Hg)	Same as [illegible] Class 1
Class 1A	-	-	-54°C to +55°C(-65° to +131°F)[3] continuous sea level (30.0 in. Hg) operation	-62° to +85°C(-80° to +185°F) (Extremes/Shock)	Operating, 30,000 feet (8.89 in Hg); nonoperating, 50,000 feet (3.4 in. Hg)	Same as [illegible] Class 1A
Class 1B	-	-	-40° to +55°C(-40° to +131°F)[3] continuous sea level (30.0 in. Hg) operation	-62° to +85°C(-80° to 185°F) (Extremes/Shock)	Operating, 15,000 feet (16.89 in. Hg); nonoperating, 50,000 feet (3.4 in. Hg)	
Class 2	-	-	-54° to +71°C(-65° to +160°F)[4] continuous sea level (30.0 in. Hg) operation	-62° to +95°C(-80° to +203°F) (Extremes/Shock)	70,000 feet (1.32 in. Hg)	Same as [illegible] Class 2
Class 3	-	-	-54° to +95°C(-65°C to +203°F)[5] continuous sea level (30.0 in. Hg) operation	-62° to +125°C(-80°F to +257°F) (Extremes/Shock)	100,000 feet (0.32 in. Hg)	Same as [illegible] Class 3
Class 4	-	-	-54° to +125°C(-65° to 257°F)[6] continuous sea level (30.0 in. Hg) operation	-62° to +150°C(-80° to +302°F) (Extremes/Shock)	100,000 feet (0.32 in. Hg)	Same as [illegible] Class 4
Class 5	-	-	-	-	-	-54°C to [illegible] +203°F)[7,illegible] continu[illegible] (30.0 in.[illegible] operation
RANGE:						
(Exposed-Unsheltered)						
1, ship or shore	-	-	-	-	-	
2, ship	-	-	-	-	-	
(Sheltered, noncontrolled environment)						
3, shore	-	-	-	-	-	
(Sheltered, controlled environment)						
4, ship or shore	-	-	-	-	-	

NOTES:

1. Equipment shall be designed to perform under the combined effects of temperature and solar radiation; it shall be based on a temperature of +52°C(+125°F) and the full impact of solar radiation of 360 BTU per square foot (105 watts per square foot) per hour for at least four hours. The 71°C(+160°F) maximum temperature is assumed to result from the combined effects of temperature and solar radiation.
2. Equipment shall perform under the combined effects of altitude and high temperature; the maximum temperature may be reduced at a rate of 1.96°C(3.5°F) per 1000 feet of elevation above sea level; e.g., temperature at 8000 feet = temp at sea level minus 1.96°C(3.5°F) times 8 = 51.6°C(125°F) minus 15.68°C(28°F) = 35.92°C(97°F)
3. +71°C maximum; intermittent operation, 30 minutes.
4. +95°C maximum; intermittent operation, 30 minutes.
5. +125°C maximum; intermittent operation, 30 minutes; 10 minutes at +150°C.
6. +150°C maximum; intermittent operation, 30 minutes; 10 minutes at +260°C(+500°F).
7. +125°C maximum; intermittent operation, 30 minutes.
8. For altitude above 100,000 feet, the equipment's surrounding environment shall not exceed 71°C and means shall be available for rejection of heat into the surroundings by conduction, radiation, or some other means.
9. +71°C maximum; intermittent operation, 20 minutes.

	MIL-E-8189F (MISSILES)			MIL-E-16400G	
Altitude	Operating	Nonoperating	Altitude	Operating	Nonoperating
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
[illegible],000 feet ([illegible] in. Hg)	Same as MIL-E-5400, Class 1	Same as MIL-E-5400, Class 1	Same as MIL-E-5400, Class 1	-	-
[illegible]rating, 30,000 feet ([illegible].89 in. Hg); nonoperating, [illegible],000 feet (3.4 in. Hg)	Same as MIL-E-5400, Class 1A	Same as MIL-E-5400, Class 1A	Same as MIL-E-5400, Class 1A	-	-
[illegible]rating, 15,000 feet ([illegible].89 in. Hg); nonoperating, [illegible],000 feet (3.4 in. Hg)	-	-	-	-	-
[illegible],000 feet ([illegible].32 in. Hg)	Same as MIL-E-5400, Class 2	Same as MIL-E-5400, Class 2	Same as MIL-E-5400, Class 2	-	-
[illegible],000 feet ([illegible].32 in. Hg)	Same as MIL-E-5400, Class 3	Same as MIL-E-5400, Class 3	Same as MIL-E-5400, Class 3	-	-
[illegible],000 feet ([illegible].32 in. Hg)	Same as MIL-E-5400, Class 4	Same as MIL-E-5400, Class 4	Same as MIL-E-5400, Class 4	-	-
-	-54°C to +95° to +203°F)[7,8] continuous sea level (30.0 in. Hg) operation	-62° to +125°C (-80° to +127°F) (Extremes/Shock)	2,000,000 feet[8] (10^{-10} in. Hg)	-	-
- -	- -	- -	- -	-54° to +65°C(-65° to +149°F) -28° to +65°C(-18° to +149°F)	-62° to +71°C(-80° to +160°F) -62° to +71°C(-80° to +160°F)
-	-	-	-	-40° to +52°C(-40° to +125°F)	-62° to +71°C(-80° to +160°F)
-	-	-	-	0° to +50°C(+32° to +122°F)	-62° to +71°C(-80° to +160°F)

Table 1 (Continued)

GENERAL SPECIFICATION	MIL-T-21200			
Temperature	Operating	Nonoperating	Altitude	
Class 1 (Airborne)	-54°C to +55°C (-65°F to +131°F)[9] continuous; sea level (30.0 in. Hg)	-62°C to +85°C (-80°F to +185°F)	50,000 feet (3.4 in. Hg)	
Class 2 (Organizational, Flight Line)	-40°C to +55°C (-40°F to +131°F)[9] continuous; sea level (30.0 in. Hg)	-62°C to +85°C (-80°F to +185°F)	Operating, 50,000 feet (3.4 in. Hg); nonoperating, 10,000 feet (20.6 in. Hg)	
Class 3 (Intermediate, Shop)	0°C to +55°C (+32°F to +131°F) continuous; sea level (30.0 in. Hg)	-62°C to +85°C (-80°F to +185°F)	Operating, 50,000 feet (3.4 in. Hg); nonoperating, 10,000 feet (20.6 in. Hg)	
Class 1	-	-	-	-54°C to +55°
Class 2	-	-	-	-40°C to +55°
Class 3	-	-	-	-15°C to +55°
Class 4	-	-	-	0°C to +55°C
Class 5	-	-	-	0°C to +50°C
Class 6	-	-	-	+10°C to +40
Class 7	-	-	-	

9 +71°C maximum; intermittent operation, 20 minutes.

AD-A031 397 NAVAL AVIONICS FACILITY INDIANAPOLIS IND F/G 9/5

STANDARD ELECTRONIC MODULES EXPLORATORY DEVELOPMENT MODULE PACK--ETC(U)

SEP 76 B D TAGUE

UNCLASSIFIED NAFI-TR-2146 NL

2 OF 2

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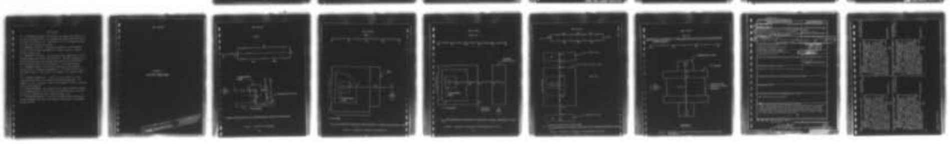

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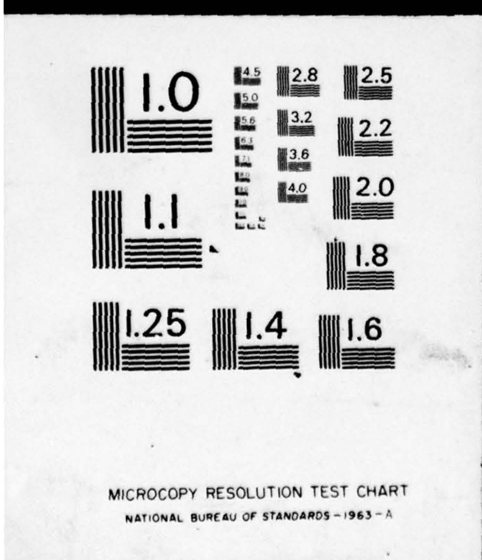
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MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

	MIL-T-28800		
Altitude	Operating	Nonoperating	Altitude
50,000 feet (3.4 in. Hg)	-	-	-
Operating, 50,000 feet (3.4 in. Hg); nonoperating, 10,000 feet (20.6 in. Hg)	-	-	-
Operating, 50,000 feet (3.4 in. Hg); nonoperating, 10,000 feet (20.6 in. Hg)	-	-	-
-	-54°C to +55°C (-65°F to +131°F)[9]	-62°C to +85°C (-80°F to +185°F)	50,000 feet (3.4 in. Hg); Operating and nonoperating
-	-40°C to +55°C (-40°F to +131°F)[9]	-62°C to +85°C (-80°F to +185°F)	Operating, 10,000 feet (20.6 in. Hg); nonoperating, 50,000 feet (3.4 in. Hg)
-	-15°C to +55°C (+5°F to +131°F)	-55°C to +75°C (-67°F to +167°F)	Operating, 10,000 feet (20.6 in. Hg); nonoperating, 50,000 feet (3.4 in. Hg)
-	0°C to +55°C (+32°F to +131°F)	-62°C to +85°C (-80°F to +185°F)	Operating, 10,000 feet (20.6 in. Hg); nonoperating, 50,000 feet (3.4 in. Hg)
-	0°C to +50°C (+32°F to +122°F)	-55°C to +75°C (-67°F to +167°F)	Operating, 10,000 feet (20.6 in. Hg); nonoperating, 50,000 feet (3.4 in. Hg)
-	+10°C to +40°C (+50°F to +104°F)	-55°C to +75°C (-67°F to +167°F)	Operating, 10,000 feet (20.6 in. Hg); nonoperating, 50,000 feet (3.4 in. Hg)
-	← To be specified in detail specification →		

Table 1 (Continued)

	MIL-E-4158 (Ground)	MIL-E-5400 (Airborne)	MIL-E-16400G (Naval Ship and Shore)	MIL-E-8189F
Fungus:				
Operating	Test per MIL-STD-454, requirement 4.	Test per MIL-STD-454, requirement 4.	Testing shall be per MIL-STD-810, method 508.	Test per MIL-STD-454, requir
Nonoperating	Test period shall not be less than 28 days.	Test period shall not be less than 28 days.		Test period shall not be less
Humidity:				
Operating	Up to 95 percent with a temperature of 26.7°C (80°F), including condensation due to temperature changes. Altitude, sea level to approximately 10,000 feet (20.6 inHg).	Up to 100 percent, including conditions wherein condensation takes place in and on the equipment.	Up to 95 percent for both continuous and intermittent periods, including conditions wherein condensation takes place in and on the equipment in the form of both water and frost.	Up to 100 percent at temperat (122°F), including conditions sation takes place in and on
Nonoperating	Up to 100 percent, including condensation due to temperature changes. Altitude, sea level to approximately 50,000 feet (3.44 inHg).	Do	Do	Do
Salt Fog (Atmosphere):	As specified in the detailed equipment specification (3.2.30.1.5).	The equipment shall withstand, in both an operating and nonoperating condition, exposure to salt-sea atmosphere. *(3.2.24.9)*	When specified in the individual equipment specification, the complete equipment or portions *thereof shall be capable of with*standing the salt fog test specified in this specification. (3.3.5.4)	The equipment shall withstand operating and nonoperating c *posure to salt-sea atmosphere.*
Shock:	When shock or vibration isolators are used, the vibration amplitude on any part shall not be more than three times the amplitude of the applied vibration at test frequencies from 10-20 cps; not more than six times at 20-55 cps. (3.2.31)	Subject equipment to 18 impact shocks of 15g, consisting of 3 shocks in opposite directions along each of 3 mutually perpen*dicular axes, each* shock impluse to have a time duration of 11 ±1 ms. (3.2.24.6)	Unless, otherwise specified, equipment shall withstand grade A, type A, class I, shock test of MIL-S-901. (3.3.5.13)	Subject equipment to 18 impac consisting *of* 3 shocks in opp along each of 3 mutually perp each shock impulse to have a 11 ±1 ms. (3.2.18.6)
Vibration:	Do	The equipment shall operate satisfactorily *when subjected to vibration within the* frequency range (5 to 2K hertz) and amplitude (0.00001 to 0.01 inch double amplitude) and as specified in the detail equipment specification. (3.2.24.5)	Unless, otherwise specified, equipment shall withstand a type I test of MIL-STD-167-1. (3.3.5.14)	Vibration requirements shall in the detail equipment spec (3.2.18.5)
Explosive Proofing:	-	This condition is satisfied when components, which in normal operation produce, or are likely to produce, sparking or arcing and which are not contained within pressurized containers, are made explosionproof. (3.2.7)	-	This condition is satisfied which in normal operation pr likely to produce, sparking which are not contained with containers, are made explosi (3.2.5)
Electromagnetic Interference:	In accordance with MIL-STD-454, requirement 61; equipments integrated into a system/subsystem shall conform to MIL-E-6051. (3.2.12)	In accordance with MIL-STD-454, requirement 61. (3.2.11)	In accordance with MIL-STD-454, requirement 61. (3.5.4)	In accordance with MIL-STD- ment 61. (3.2.6)
Corrosion Resistance:	-	Ferrous alloys shall be in accordance with MIL-STD-454, requirement 15. (3.1.6)	In accordance with MIL-STD-454, requirement 15. (3.4.11.2)	Ferrous alloys shall be in ac MIL-STD-454, requirement 15.
Enclosure:	In accordance with MIL-STD-454, requirement 55. (3.2.14)	In accordance with MIL-STD-454, requirement 55. (3.2.5)	In accordance with MIL-STD-454, requirement 55, and MIL-STD-108. (3.7.2)	-
Thermal Design:	In accordance with MIL-STD-454, requirement 52. (3.2.26)	In accordance with MIL-STD-454, requirement 52. (3.2.5)	In accordance with MIL-STD-454, requirement 52. (3.8)	Cooling provisions and therm be in accordance with MIL-ST ment 52. (3.2.3)
Moisture Pockets:	In accordance with MIL-STD-454, requirement 31. (3.2.25)	In accordance with MIL-STD-454, requirement 31. (3.2.17)	In accordance with MIL-STD-454, requirement 31. (3.7.2.6)	In accordance with MIL-STD- ment 31. (3.2.12)

	MIL-E-8189F	MIL-T-21200	MIL-T-28800
od 508.	Test per MIL-STD-454, requirement 4. Test period shall not be less than 28 days.	Test per MIL-STD-454, requirement 4. Test period shall not be less than 28 days.	Equipments shall be inherently fungus-inert through materials control. When required in the detailed specification, verification testing shall be conducted as specified herein.
ions ter	Up to 100 percent at temperatures up to 50°C (122°F), including conditions wherein condensation takes place in and on the equipment.	Up to 100 percent, including conditions wherein condensation takes place in and on the equipment.	Up to 100 percent for Classes 1 to 4; 95%, Classes 5 and 6; and, as required in the detailed specification for Class 7 equipment.
	Do	Do	Do
ent or ith- n	The equipment shall withstand, in both an operating and nonoperating condition, exposure to salt-sea atmosphere. (3.2.18.9)	The equipment shall withstand, in both an operating and nonoperating condition, exposure to salt-sea atmosphere. (3.2.19.8)	Unless otherwise required by the detailed specification, tests shall be as specified herein.
shall ck	Subject equipment to 18 impact shocks of 15g, consisting of 3 shocks in opposite directions along each of 3 mutually perpendicular axes, each shock impulse to have a time duration of 11 ±1 ms. (3.2.18.6)	Subject equipment to 18 impact shocks of 15g, consisting of 3 shocks in opposite directions along each of 3 mutually perpendicular axes, each shock impulse to have a time duration of 11 ±1 ms. (3.2.19.5.1)	Subject Class 1, 2, 4, 5, 6 equipment to 18 impact shocks of 15g; Class 3, 30g's; and Class 7 as specified in the detailed specification.
shall -1.	Vibration requirements shall be as specified in the detail equipment specification. (3.2.18.5)	Vibration tests shall be in accordance with MIL-T-5422 for the Navy and MIL-STD-810 for the Air Force and Army to limits specified in the detail specification.	Unless otherwise required in the detailed specification, all classes shall meet the specified performance and accuracy requirements specified herein.
	This condition is satisfied when components, which in normal operation produce, or are likely to produce, sparking or arcing and which are not contained within pressurized containers, are made explosion-proof. (3.2.5)	The equipment shall not cause ignition of an ambient-explosive-gaseous mixture with air when operating in such an atmosphere.	The operation of Class 1 and 2 (and Class 4 equipment when required in the detailed specification), shall not cause ignition of an ambient-explosive-gaseous mixture with air.
	In accordance with MIL-STD-454, requirement 61. (3.2.6)	In accordance with MIL-STD-454, requirement 61. (3.2.10)	Unless otherwise specified in the detailed specification, EMI control shall be in accordance with MIL-STD-461, and as specified herein.
	Ferrous alloys shall be in accordance with MIL-STD-454, requirement 15. (3.1.6)	In accordance with MIL-STD-454, requirement 15. (3.1.6.7)	-
	-	In accordance with MIL-STD-454, requirement 55. (3.2.3)	-
	Cooling provisions and thermal design shall be in accordance with MIL-STD-454, requirement 52. (3.2.3)	In accordance with MIL-STD-454, requirement 52. (3.2.5)	-
	In accordance with MIL-STD-454, requirement 31. (3.2.12)	In accordance with MIL-STD-454, requirement 31. (3.2.15)	-

Table 2

AIR FORCE

System/ Equipment	Temperature		Fungus	Humidity		Shock	Vibration	Enclosure	Salt Spray	Altitude
	Operating	Non-Operating		Operating	Non-Operating					
AN/UPM-12A Radar Test Set (7)	-20° to +71°C	-20° to +85°C	MIL-STD-810 Method 508, Procedure I	95%	95%	Six shocks of 30g at a time duration of 10 ms	10 to 55 Hz	MIL-STD-108	MIL-STD-810 Method 509 Procedure I	10,000 feet operation; 50,000 feet nonoperation
AN/FCC-17( ) Multiplexer Set (2)(7)	-54° to +71°C	-62° to +71°C	MIL-STD-810 Method 508, Procedure I	MIL-STD-810 Method 507, Procedure I	MIL-STD-810 Method 507, Procedure I	MIL-STD-810 Method 516, Procedure I	MIL-STD-810 Method 514, Procedure I	-	MIL-STD-810 Method 509, Procedure I	MIL-STD-810 Method 500, Procedure I
AN/PRC-72 Radio Set (1)(9)	-30° to +52°C	-54° to +68°C	MIL-STD-810 Method 508, Procedure I	MIL-STD-810 Method 507, Procedure I	MIL-STD-810 Method 507, Procedure I	-	MIL-STD-810 Method 514, Procedure I	-	MIL-STD-810 Method 509, Procedure I	MIL-STD-810 Method 500, Procedure I
OA-4103( )/ GRC Multiplexer Group (2)(7)	-54° to +71°C	-62° to +71°C	MIL-STD-810 Method 508, Procedure I	MIL-STD-810 Method 507, Procedure I	MIL-STD-810 Method 507, Procedure I	MIL-STD-810 Method 516, Procedure I	MIL-STD-810 Method 514, Procedure I	-	MIL-STD-810 Method 509, Procedure I	MIL-STD-810 Method 500, Procedure I
V-221( )/ MCC-12 Trailer (3)	-54° to +71°C	-62° to +71°C	MIL-STD-810 Method 508, Procedure I	MIL-STD-810 Method 507, Procedure I	MIL-STD-810 Method 507, Procedure I	MIL-STD-810 Method 516, Procedure I	MIL-STD-810 Method 514, Procedure I	-	MIL-STD-810 Method 509, Procedure I	MIL-STD-810 Method 500, Procedure I
AN/PRC-71( ) Radio Set (1)(9)	-30° to +52°C	-52° to +68°C	Per paragraph 4.6.4.1.c of MIL-R-27838	MIL-STD-810 Method 507, Procedure I	MIL-STD-810 Method 507, Procedure I	MIL-STD-810 Method 516, Procedure I	MIL-STD-810 Method 514, Procedure I	-	MIL-STD-810 Method 509, Procedure I	MIL-STD-810 Method 500, Procedure I
AN/UPA-56( ) Indicator Group (6)	0° to +49°C	-62° to +71°C	Per detail specification	96%	100%	Per detail specification	Per detail specification	-	Per detail specification	12,000 feet operation; 50,000 feet nonoperation
CW-860/ GPS( ) Radome (2)	-54° to +71°C	-62° to +71°C	MIL-STD-454 Reqt. 4	MIL-STD-810 Method 507, Procedure I	MIL-STD-810 Method 507, Procedure I	MIL-STD-810 Method 516, Procedures I and V	MIL-STD-810 Method 514, Procedures X and XI	-	MIL-STD-810 Method 509, Procedure I	10,000 feet operation; 50,000 feet nonoperation
MXU-465/A Multiplexer (6)	-54° to +71°C	-62° to +95°C	MIL-STD-810 Method 508, Procedure I	MIL-STD-810 Method 507, Procedure I	MIL-STD-810 Method 507, Procedure I	MIL-STD-810 Method 516, Procedure I	MIL-STD-810 Method 514, Procedure IBIC	-	MIL-STD-810 Method 509, Procedure I	80,000 feet
C5A Inertial Doppler Navigation Equipment (6)	-54° to +55°C	-62° to +85°C	MIL-STD-810 Method 508.1, Procedure I	MIL-STD-810 Method 507.1, Procedure I	MIL-STD-810 Method 507.1, Procedure I	MIL-STD-810 Method 516.1, Procedures I and IV	MIL-STD-810 Method 514.1, Procedure I	-	MIL-STD-810 Method 509.1, Procedure I	MIL-STD-810 Method 500.1, Procedure I 50,000 feet max.
AN/ARC-109 UHF Radio (6)	-54° to +55°C	-62° to +85°C	MIL-STD-810 Method 508.1, Procedure I	MIL-STD-810 Method 507.1, Procedure I	MIL-STD-810 Method 507.1, Procedure I	MIL-STD-810 Method 516.1, Procedures I and IV	MIL-STD-810 Method 514.1 Procedure I	-	MIL-STD-810 Method 509.1, Procedure I	MIL-STD-810 Method 500.1, Procedure I 50,000 feet max.
VHF/AM Radio (6)	-54° to +55°C	-62° to +85°C	MIL-STD-810 Method 508.1, Procedure I	MIL-STD-810 Method 507.1, Procedure I	MIL-STD-810 Method 507.1, Procedure I	MIL-STD-810 Method 516.1, Procedures I and IV	MIL-STD-810 Method 514.1 Procedure I	-	MIL-STD-810 Method 509.1, Procedure I	MIL-STD-810 Method 500.1, Procedure I 50,000 feet max.
VHF/FM Radio (6)	-54° to +55°C	-62° to +85°C	MIL-STD-810 Method 508.1, Procedure I	MIL-STD-810 Method 507.1, Procedure I	MIL-STD-810 Method 507.1, Procedure I	MIL-STD-810 Method 516.1, Procedures I and IV	MIL-STD-810 Method 514.1 Procedure I	-	MIL-STD-810 Method 509.1, Procedure	MIL-STD-810 Method 500.1, Procedure I 50,000 feet max.
HF/SSB Radio (6)	-54° to +55°C	-62° to +85°C	MIL-STD-810 Method 508.1, Procedure I	MIL-STD-810 Method 507.1, Procedure I	MIL-STD-810 Method 507.1, Procedure I	MIL-STD-810 Method 516.1, Procedures I and IV	MIL-STD-810 Method 514.1 Procedure I	-	MIL-STD-810 Method 509.1, Procedure I	MIL-STD-810 Method 500.1, Procedure I 50,000 feet max.
AN/APX-64(V) IFF (6)	-54° to +55°C	-62° to +85°C	MIL-STD-810 Method 508.1 Procedure I	MIL-STD-810 Method 507.1, Procedure I	MIL-STD-810 Method 507.1, Procedure I	MIL-STD-810 Method 516.1, Procedures I and IV	MIL-STD-810 Method 514.1 Procedure I	-	MIL-STD-810 Method 509.1, Procedure I	MIL-STD-810 Method 500.1, Procedure I 50,000 feet max.
Crash Position Indicator (6)	-54° to +55°C	-62° to +85°C	MIL-STD-810 Method 508.1, Procedure I	MIL-STD-810 Method 507.1, Procedure I	MIL-STD-810 Method 507.1, Procedure I	MIL-STD-810 Method 516.1, Procedures I and IV	MIL-STD-810 Method 514.1 Procedure I	-	MIL-STD-810 Method 509.1, Procedure I	MIL-STD-810 Method 500.1, Procedure I 50,000 feet max.
Attitude Heading Ref. System (6)	-54° to +55°C	-62° to +85°C	MIL-STD-810 Method 508.1 Procedure I	MIL-STD-810 Method 507.1, Procedure I	MIL-STD-810 Method 507.1, Procedure I	MIL-STD-810 Method 516.1, Procedures I and IV	MIL-STD-810 Method 514.1 Procedure I	-	MIL-STD-810 Method 509.1, Procedure I	MIL-STD-810 Method 500.1, Procedure I 50,000 feet max.
ADF (6)	-54° to +55°C	-62° to +85°C	MIL-STD-810 Method 508.1, Procedure I	MIL-STD-810 Method 507.1, Procedure I	MIL-STD-810 Method 507.1, Procedure I	MIL-STD-810 Method 516.1, Procedures I and IV	MIL-STD-810 Method 514.1 Procedure I	-	MIL-STD-810 Method 509.1, Procedure I	MIL-STD-810 Method 500.1, Procedure I 50,000 feet max.

Table 2 (Cont.)

AIR FORCE

System/ Equipment	Temperature		Fungus	Humidity		Shock	Vibration	Enclosure	Salt Spray	Altitude
	Operating	Non-Operating		Operating	Non-Operating					
LORAN (6)	-54° to +55°C	-62° to +85°C	MIL-STD-810 Method 508.1, Procedure I	MIL-STD-810 Method 507.1, Procedure I	MIL-STD-810 Method 507.1, Procedure I	MIL-STD-810 Method 516.1, Procedures I and IV	MIL-STD-810 Method 514.1 Procedure I	-	MIL-STD-810 Method 509.1, Procedure I	MIL-STD-810 Method 500.1, Procedure I 50,000 feet max.
Marker Beacon (6)	-54° to +55°C	-62° to +85°C	MIL-STD-810 Method 508.1, Procedure I	MIL-STD-810 Method 507.1, Procedure I	MIL-STD-810 Method 507.1, Procedure I	MIL-STD-810 Method 516.1, Procedures I and IV	MIL-STD-810 Method 514.1 Procedure I	-	MIL-STD-810 Method 509.1, Procedure I	MIL-STD-801 Method 500.1, Procedure I 50,000 feet max.
Glide Slope (6)	-54° to +55°C	-62° to +85°C	MIL-STD-810 Method 508.1, Procedure I	MIL-STD-810 Method 507.1, Procedure I	MIL-STD-810 Method 507.1, Procedure I	MIL-STD-810 Method 516.1, Procedures I and IV	MIL-STD-810 Method 514.1 Procedure I	-	MIL-STD-810 Method 509.1, Procedure I	MIL-STD-801 Method 500.1, Procedure I 50,000 feet max.
VHF Navigation (ILS) (6)	-54° to +55°C	-62° to +85°C	MIL-STD-810 Method 508.1, Procedure I	MIL-STD-810 Method 507.1, Procedure I	MIL-STD-810 Method 507.1, Procedure I	MIL-STD-810 Method 516.1, Procedures I and IV	MIL-STD-810 Method 514.1 Procedure I	-	MIL-STD-810 Method 509.1, Procedure I	MIL-STD-801 Method 500.1, Procedure I 50,000 feet max.
TACAN (6)	-54° to +55°C	-62° to +85°C	MIL-STD-810 Method 508.1, Procedure I	MIL-STD-810 Method 507.1, Procedure I	MIL-STD-810 Method 507.1, Procedure I	MIL-STD-810 Method 516.1, Procedures I and IV	MIL-STD-810 Method 514.1 Procedure I	-	MIL-STD-810 Method 509.1, Procedure I	MIL-STD-801 Method 500.1, Procedure I 50,000 feet max.
Inertial Doppler Navigation System (6)	-54° to +55°C	-62° to +85°C	MIL-STD-810 Method 508.1, Procedure I	MIL-STD-810 Method 507.1, Procedure I	MIL-STD-810 Method 507.1, Procedure I	MIL-STD-810 Method 516.1, Procedures I and IV	MIL-STD-810 Method 514.1 Procedure I	-	MIL-STD-810 Method 509.1, Procedure I	MIL-STD-801 Method 500.1, Procedure I 50,000 feet max.
Multimode Radar (6)	-54° to +55°C	-62° to +85°C	MIL-STD-810 Method 508.1, Procedure I	MIL-STD-810 Method 507.1, Procedure I	MIL-STD-810 Method 507.1, Procedure I	MIL-STD-810 Method 516.1, Procedures I and IV	MIL-STD-810 Method 514.1 Procedure I	-	MIL-STD-810 Method 509.1, Procedure I	MIL-STD-801 Method 500.1, Procedure I 50,000 feet max.
Radar Altimeter (6)	-54° to +55°C	-62° to +85°C	MIL-STD-810 Method 508.1, Procedure I	MIL-STD-810 Method 507.1, Procedure I	MIL-STD-810 Method 507.1, Procedure I	MIL-STD-810 Method 516.1, Procedures I and IV	MIL-STD-810 Method 514.1 Procedure I	-	MIL-STD-810 Method 509.1, Procedure I	MIL-STD-801 Method 500.1, Procedure I 50,000 feet max.

USAGE:

(1) Man Pack
(2) Ground Based (Sheltered)
(3) Mobile Van
(4) Shipboard
(5) Submarine
(6) Avionics - General
(7) Ground Support Equipment
(8) Avionics - High Performance
(9) Mobile - Jeep
(10) Portable

Table 3

NAVY

System/ Equipment	Temperature		Fungus	Humidity		Shock	Vibration	Enclosure	Salt Spray	Altitude
	Operating	Non-Operating		Operating	Non-Operating					
AN/BQQ-6 Sonar System (5)	0° to 50°C	-18° to +75°C	MIL-STD-454 reqt 4	95%	95%	MIL-S-901 Grade A, Type A Class I or II	MIL-STD-167 Type I 4 to 33 Hz	MIL-STD-454 reqt 55 or MIL-STD-108	FED-STD No. 151 method 811.1 or ASTM B117	-
AN/SPS-49 Radar Set (4)	0° to 50°C	-62° to +71°C, except Class 2 exposed equipment, +100°C	MIL-STD-454 reqt 4	95%	95%	MIL-S-901 Grade A, Class I	MIL-STD-167 Type I	MIL-STD-108	FED-STD No. 151 method 811.1	-
AN/SQN-17 Bottom Topography Survey Subsystem (4)	0° to 50°C	-62° to 71°C		95%	95%		MIL-STD-167 Type I	-	-	- -
AN/SQR-18 Tactical Towed Array System (4)	0° to 50°C	-10° to 65°C in air; 0° to 35°C in water		50%	-		-	-	-	-
AN/BQQ-5 Sonar System (5)	0° to 50°C	-18° to +75°C	MIL-STD-454 reqt 4	95%	95%	MIL-S-901 Grade A, Class I	MIL-STD-167 Type I	MIL-STD-108	FED-STD No. 151 method 811.1	-
AN/BQR-24 Sonar Receiving Set (5)	0° to 50°C	-18° to +75°C	MIL-STD-454 reqt 4	95%	95%	MIL-S-901 Grade A, Class I	MIL-STD-167 Type I	MIL-STD-108	FED-STD No. 151 method 811.1	-
AN/APS-88 Radar Set (6)	-54 to +55°C	-62° to +85°C	MIL-T-5422 reqts	90%	90%	MIL-T-5422 reqts	MIL-E-5400 Curves I and II	-	MIL-T-5422 reqts	To 30,000 feet
AN/APN-141(V) Altimeter Set (8)	-54° to +95°C	-62° to +125°C	MIL-T-5422 reqts	100%	100%	18 impacts of 15g at a time duration of 11 ±1 ms	Freq 5 to 500 Hz at a max. acceleration of ±10g	-	MIL-T-5422 reqts	To 60,000 feet
AN/ASN-51 Display Set (4)	-54° to +71°C	-62° to +95°C	-	90%	90%	-	MIL-E-5400 Curves I and II	-	-	-
AN/ALE-41 Dispensing Set Counter-Measures, Chaff (8)	-54° to +55°C	-62° to +85°C	-	90%	90%	-	MIL-E-5400 Curve I	-	-	-
AN/SSQ-23 Sonobuoy (6)	-54° to +55°C	-62° to +85°C	MIL-T-5422 reqts	-	-	6 impacts of 100g at a time duration of 11 ±1 ms	MIL-T-5422 reqts	-	MIL-T-5422 reqts	Up to 35,000 feet
AN/SRC-22 Communication System, Flight Deck (4)	0° to 50°C	-62° to +71°C	MIL-STD-454 reqt 4	95%	95%	MIL-S-901 Grade A, Type B, Class I	MIL-STD-167 Type I	MIL-STD-108	FED-STD No. 151 method 811.1	-
T-751( )/AJB-3 Xmtr,Rate Gyro (6)	-54° to +71°C	-62° to +95°C	MIL-T-5422 reqts	90%	90%		MIL-E-5400 Curve III	-	MIL-T-5422 reqts	70,000 feet
AN/UPM-136 Radar Test Set (6)	-28° to +65°C	-62° to +75°C	MIL-STD-454 reqt 4	95%	95%	MIL-S-901 Grade A, Type A, Class I	MIL-STD-167 Type I	MIL-STD-108	FED-STD No. 151 method 811.1	10,000 operating; 50,000 feet, nonoperating
AN/WLR-11 Electronic Countermeasures Receiving Set (4)(5)	-28° to +65°C	-62° to +71°C	MIL-STD-454 reqt 4	95%	95%	MIL-S-901 Type A, Class I	MIL-STD-167 Type I	MIL-STD-454 reqt 55	FED-STD No. 151 method 811.1	-

Table 3 (Cont.)

NAVY

System/ Equipment	Temperature		Fungus	Humidity		Shock	Vibration	Enclosure	Salt Spray	Altitude
	Operating	Non-Operating		Operating	Non-Operating					
Defense Weapons System (5)	0° to 50°C	-18° to +75°C	MIL-STD-454 reqt 4	100%	100%	MIL-S-901 Grade A, Type A, Class I	MIL-STD-167 Type I	MIL-STD-108	FED-STD No. 151 method 811.1	To 50,000 feet
Command Subsystem (5)	0° to 50°C	-18° to +75°C	MIL-STD-454 reqt 4	100%	100%	MIL-S-901 Grade A, Type A, Class I	MIL-STD-167 Type I	MIL-STD-108	FED-STD No. 151 method 811.1	To 50,000 feet
Tactical Navigation System (5)	0° to 50°C	-18° to +75°C	MIL-STD-454 reqt 4	100%	100%	MIL-S-901 Grade A, Type A, Class I	MIL-STD-167 Type I	MIL-STD-108	FED-STD No. 151 method 811.1	To 50,000 feet
Exterior Communications System (5)	0° to 50°C	-18° to +75°C	MIL-STD-454 reqt 4	100%	100%	MIL-S-901 Grade A, Type A, Class I	MIL-STD-167 Type I	MIL-STD-108	FED-STD No. 151 method 811.1	To 50,000 feet
Interior Communications System (5)	0° to 50°C	-18° to +75°C	MIL-STD-454 reqt 4	100%	100%	MIL-S-901 Grade A, Type A, Class I	MIL-STD-167 Type I	MIL-STD-108	FED-STD No. 151 method 811.1	To 50,000 feet
Radar Subsystem (5)	0° to 50°C	-18° to +75°C	MIL-STD-454 reqt 4	100%	100%	MIL-S-901 Grade A, Type A, Class I	MIL-STD-167 Type I	MIL-STD-108	FED-STD No. 151 method 811.1	To 50,000 feet
IFF Subsystem (5)	0° to 50°C	-18° to +75°C	MIL-STD-454 reqt 4	100%	100%	MIL-S-901 Grade A, Type A, Class I	MIL-STD-167 Type I	MIL-STD-108	FED-STD No. 151 method 811.1	To 50,000 feet
Periscope Subsystem (5)	0° to 50°C	-18° to +75°C	MIL-STD-454 reqt 4	100%	100%	MIL-S-901 Grade A, Type A, Class I	MIL-STD-167 Type I	MIL-STD-108	FED-STD No. 151 method 811.1	To 50,000 feet
Monitoring Subsystem (5)	0° to 50°C	-18° to +75°C	MIL-STD-454 reqt 4	100%	100%	MIL-S-901 Grade A, Type A, Class I	MIL-STD-167 Type I	MIL-STD-108	FED-STD No. 151 method 811.1	To 50,000 feet
Central Computer Complex (5)	0° to 50°C	-18° to +75°C	MIL-STD-454 reqt 4	100%	100%	MIL-S-901 Grade A, Type A, Class I	MIL-STD-167 Type I	MIL-STD-108	FED-STD- No. 151 method 811.1	To 50,000 feet
Standard Information Display Subsystem (5)	0° to 50°C	-18° to +75°C	MIL-STD-454 reqt 4	100%	100%	MIL-S-901 Grade A, Type A, Class I	MIL-STD-167 Type I	MIL-STD-108	FED-STD No. 151 method 811.1	To 50,000 feet
AN/SQS-26 Sonar System (4)	0° to 50°C	-62° to +75°C, except SHP modules NLT -55°C	MIL-STD-454 reqt 4	95%	95%	MIL-S-901 Grade A, Class II	MIL-STD-167 Type I	MIL-STD-108	Not required	-
AN/SQS-53 Sonar System (4)	0° to 50°C	-62° to 75°C	MIL-STD-454 reqt 4	95%	95%	MIL-S-901 Grade A, Class II	MIL-STD-167 Type I	MIL-STD-108	Not required	-
AN/SQS-53A Sonar System (4)	0° to 50°C	-62° to +75°C	MIL-STD-454 reqt 4	95%	95%	MIL-S-901 Grade A, Class II	MIL-STD-167 Type I	MIL-STD-108	Not required	-
AN/SQS-35 Independent Variable Depth Sonar (4) System	0° to 50°C	-62° to +75°C	MIL-STD-454 reqt 4	95%	95%	MIL-S-901 Grade A, Class I	MIL-STD-167 Type I	MIL-STD-108	-	-
AN/SQS-38 Hull Sonar System (4)	0° to 50°C	-62° to +75°C	MIL-STD-454 reqt 4	95%	95%	MIL-S-901 Grade A, Type I, Class I	MIL-STD-167 Type I	MIL-STD-108	-	-
AN/SQS-56 Sonar System (4)	0° to 50°C	-62° to +75°C	MIL-STD-454 reqt 4	95%	95%	MIL-S-901 Grade A, Type I, Class I	MIL-STD-167 Type I	MIL-STD-108	-	50,000 feet (during transport)

USAGE:

(1) Man Pack
(2) Ground Based (Sheltered)
(3) Mobile Van
(4) Shipboard
(5) Submarine
(6) Avionics - General
(7) Ground Support Equipment
(8) Avionics - High Performance
(9) Mobile - Jeep
(10) Portable

Table 4

ARMY

System/ Equipment	Temperature: Operating	Temperature: Non-Operating	Fungus	Humidity: Operating	Humidity: Non-Operating	Shock	Vibration	Enclosure	Salt Spray	Altitude
AN/GLQ-2( ) Radio Set (2)	-54° to +66°C	-62° to +71°C	MIL-T-152	97%	97%	Per detail specification	10 to 55 Hz	-	-	10,000 feet, operating; 50,000 feet, nonoperating
AN/PRC-77 Radio Set (1)(9)	-40° to +65°C	-62° to +71°C	MIL-STD-810 Method 508	97%	97%	Per detail specification	10 to 55 Hz	-	MIL-STD-810 Method 509	10,000 feet, operating; 40,000 feet, nonoperating
AN/PRC-25 Radio Set (1)(9)	-40° to +65°C	-62° to +71°C	MIL-STD-810 Method 508	97%	97%	Per detail specification	10 to 55 Hz	-	MIL-STD-810 Method 509	10,000 feet, operating; 50,000 feet, nonoperating
T4138 Test Set, 6A1 Test Programmer (7)	-18° to +54°C	-54° to +71°C	MIL-STD-810 Method 508	95%	95%	18 impacts of 30g at a time duration of 11 ms each	Per detail specification	-	-	-
AN/GSQ-160 Detecting-Transmitting Set, Electro-magnetic (10)	+1° to +64°C	-57° to +74°C	MIL-STD-810 Method 508, Procedure I	94%	94%	Per detail specification	10 to 55 Hz	-	Per detail specification	10,000 feet, operating; 50,000 feet, nonoperating
AN/FGC-25( ) Teletypewriter Set (2)	0° to +55°C	-65° to +71°C	-	MIL-STD-810 Method 507, Procedure I	MIL-STD-810 Method 507, Procedure I	MIL-STD-810 Method 516, Procedure I	MIL-STD-810 Method 514, Procedure IX Part 1	-	-	MIL-STD-810 Method 500, Procedure I
AN/APM-123(V) Transponder Test Set(7)	-40° to +55°C	-62° to +85°C	MIL-STD-810 Method 508	97%	97%	Per detail specification	10 to 55 Hz	-	FED-STD No. 151 Method 811.1	10,000 feet, operating; 50,000 feet, nonoperating
AN/TPM-25 Radar Test Set (7)	0° to +55°C	-62° to +85°C	MIL-STD-810 Method 508, Procedure I	100%	100%	MIL-STD-810 Method 516.1 Procedure V	5 to 55 Hz	-	MIL-STD-810 Method 509	10,000 feet, operating; 50,000 feet, nonoperating
AN/USM-410(XE-3)(V) Electronic Equipment Test Station (7)	+20° to +35°C	0° to +50°C	MIL-STD-454 Reqt 4	90%	90%	-	-	MIL-STD-454 Reqt 55	-	-
Transceiver, MF-HF-VHF, Vehicular and Man-Pack (1)(9)	-40° to +65°C	-53° to +68°C	-	100%	100%	Per detail specification	10 to 55 Hz	-	MIL-STD-202 Method 101, Condition B	10,000 feet, operating; 50,000 feet, nonoperating
AN/GSG-10(V) Fire Direction System, Artillery (7)	-40° to +52°C	-62° to +68°C	-	100%	100%	Operating, Type I, 5g; Type II, 20g; Nonoperating, vehicular, 10g; air drop, 30g	10 to 55 Hz	-	-	-1300 to 10,000 feet operating; -1300 to 40,000 feet nonoperating
AN/APM-305 Transponder, Test Set (7)	0° to +55°C	-62° to +85°C	MIL-STD-810 Method 508	100%	100%	MIL-STD-810 Method 516.1 Procedure V	5 to 55 Hz	-	MIL-STD-810 Method 509	10,000 feet, operating; 50,000 feet, nonoperating
AN/ARN-89( ) Direction Finder Set (8)	-54° to +55°C	-62° to +85°C	MIL-STD-810 Method 508	100%	100%	MIL-T-5422 Parts I and II	MIL-T-5422 Curve III, Figure 5	-	MIL-STD-810 Method 509	Up to 50,000 feet, operating
AN/ARC-115( ) Radio Set (6)	-54° to +55°C	-62° to +85°C	MIL-STD-810 Method 508	100%	100%	MIL-T-5422 Parts I and II	MIL-T-5422	-	MIL-STD-810 Method 509	Up to 50,000 feet, operating
AN/PRC-70( ) Radio Set (1)(9)	-46° to +52°C	-57° to +71°C	MIL-STD-810 Method 508, Procedure I	MIL-STD-810 Method 507, Procedure III	MIL-STD-810 Method 507, Procedure III	MIL-STD-810 Method 516, Procedures II and V	10 to 55 Hz	-	MIL-STD-810 Method 509, Procedure I	10,000 feet, operating; 50,000 feet, nonoperating
AN/GMD-1 Rawin Set(2)(7)	-54° to +66°C	-62° to +71°C	MIL-STD-810 Method 508, Procedure I	97%	97%	Per detail specification	-	-	MIL-STD-810 Method 509	-
AN/PMQ-1 Meteorological Station (2)	-59° to +66°C	-62° to +71°C	MIL-STD-810 Method 508	97%	97%	-	-	-	-	10,000 feet, operating

Table 4 (Cont.)

ARMY

System/ Equipment	Temperature		Fungus	Humidity		Shock	Vibration	Enclosure	Salt Spray	Altitude
	Operating	Non-Operating		Operating	Non-Operating					
AN/AMT-4( ) Radiosonde Set (7)	-57° to +71°C	-57° to +71°C	MIL-STD-810 Method 508, Procedure I	MIL-STD-810 Method 507, Procedure II	MIL-STD-810 Method 507, Procedure II	MIL-STD-810 Method 516, Procedure II	MIL-STD-810 Method 514, Procedure XI, Parts 1 and 2	-	-	Up to 105,000 feet, operating
AN/TPM-22 Radar Test Set (7)	0°C to +55°C	-62° to +85°C	-	95%	95%	Per detail specification	5 to 55 Hz	-	-	10,000 feet, operating; 40,000 feet, nonoperating
AN/ARN-103(V) TACAN Navigation Set (6)	-54° to +71°C	-62° to +95°C	-	95%	95%	18 impacts of 15g at a time duration of 11 ms each	-	-	-	30,000 feet, operating, 50,000 feet, nonoperating

USAGE:

(1) Man Pack
(2) Ground Based (Sheltered)
(3) Mobile Van
(4) Shipboard
(5) Submarine
(6) Avionics - General
(7) Ground Support Equipment
(8) Avionics - High Performance
(9) Mobile - Jeep
(10) Portable

APPENDIX D

SEM TRADE-OFF CRITERIA AND DEFINITIONS

SEM TRADE-OFF CRITERIA AND DEFINITIONS

1. MODULE COST - The relative projected production cost of the module. The projection is related to size, producibility, complexity, density and technology restrictions.
2. NUMBER OF PINS/ACTIVE MODULE PACKAGING AREA - The number of pins divided by the total maximum module packaging surface.
3. COST/IC - The "Module Cost" as defined in criteria #1 divided by the number of IC's. The number of IC's is a weighted average of 16 pin dips and 16 pin flat packs.
4. ASPECT RATIO - The <u>average</u> of the module and circuit board aspect ratios. The module aspect is defined as the over-all height of the module divided by the over-all width of the module. This includes any cooling fins, side guides, connectors, keying pins and screw heads. The circuit board aspect ratio is defined as the over-all height of the active circuit board divided by the over-all width of the active circuit board. The active circuit board is defined as the area that can actually be used to mount electrical components. This area may be different from the total area and may also be different for different technologies (e.g., flat packs which would allow usage of both sides.)
5. PIN SPACING - The spacing or distance between connector pin centers. This spacing is measured in both the X and Y dimensions. This factor also considers the grid pattern (e.g., rectangular, diagonal).
6. NUMBER OF PINS - A simple count of the connector pins that are needed to accommodate efficiently the range of function levels having system commonality.
7. THERMAL RESISTANCE - Thermal resistance, defined as degrees Centigrade/Watt, measured from the hot spot on the component case to the worst case module thermal interface point.
8. DEGREES CENTIGRADE/WATT/BOARD AREA - Thermal resistance, defined as degrees Centigrade/Watt multiplied by the maximum board area. The maximum board area is defined as in criteria #4. The thermal resistance is measured from the module thermal interface point to the system heat sink.
9. WATTS/VOLUME - DEGREES CENTIGRADE - The summation of internal and external thermal resistance inverted and divided by the module volume.

(Module volume is defined as the over-all height of the module times the over-all width of the module times the over-all thickness of the module, including any cooling fins, side guides, connectors, keying pins and screw heads. Sometimes called the "slot volume".)

10. EXTRACTION/INSERTION FORCE - The force required to insert and extract the module from its operating position after all restraints, locking devices, etc., have been removed.

11. RELIABILITY/IC - The over-all reliability of the module divided by the number of "IC's" that can be placed on a module.

12. RELIABILITY, MECHANICAL - The reliability of the module after the reliability of the electrical components have been subtracted out.

13. QUALITY - The relative ability to insure module quality through normal inspection and test procedures. Related to size, complexity, density and technology.

14. APPLICATION FLEXIBILITY, MECHANICAL - The capability of the module mechanical design to be used in a wide variety of supporting structures (enclosures, racks, ATR's, etc.) and with different thermal interfaces.

15. TESTABILITY - A measure of the ease with which the module may be tested. Related to the number of gates/pin on the module.

16. PRODUCIBILITY - A measure of the ease with which a particular module design may be produced. This is a complex of all those factors that can influence the ease of fabrication, such as, mechanical tolerances, special processes, tooling and the existence of automatic machinery.

17. VOLUME/IC - The module volume (defined as in #9) divided by the number of IC's that can be placed on a module. The number of IC's is a weighted average of 16-pin dips and 16-pin flat packs.

18. ENVIRONMENTAL FLEXIBILITY REQUIREMENTS - The capability of the module design to meet the different environmental requirements.

19. FUNCTIONAL FLEXIBILITY - The capability of the module design to accommodate efficiently the range of function levels projected to have system commonality. Efficiency is defined as: (board area used/board total area) X (pins used/pins available.)

20. WEIGHT/IC - The overall weight of a module with IC's divided by the maximum number of IC's that can be placed on the module. The number of IC's is a weighted average of 16-pin dips and 16-pin flat packs.

21. IC OPERATING COST/HOUR - The "module cost" taken from criteria #1 divided by the number of IC's on the module time the failure rate of the IC's taken from criteria #11. The number of IC's is a weighted average of 16-pin dips and 16-pin flat packs.

22. CONNECTOR FLEXIBILITY - The relative capability of the connector design to meet different requirements of voltage, current, frequency, contact resistance, etc.

23. COMPATIBILITY WITH SEM - The relative one-way compatibility of the candidate module with the existing SEM module. (One way compatibility is defined as being able to mix without severe penalty existing SEM form factor modules and new form factor modules in a new system design.)

24. INCREMENTAL GROWTH - The relative capability of the candidate module design to be expanded incrementally. This includes the effect of incremental growth on size, weight, cost, aspect ratio, number of pins, etc.

25. TECHNOLOGY COMPATIBILITY - A measure of the flexibility of the candidate module design with respect to differing technologies. For example, can dips, flat packs, custom LSI and hybrid circuits all be used without severe penalty?

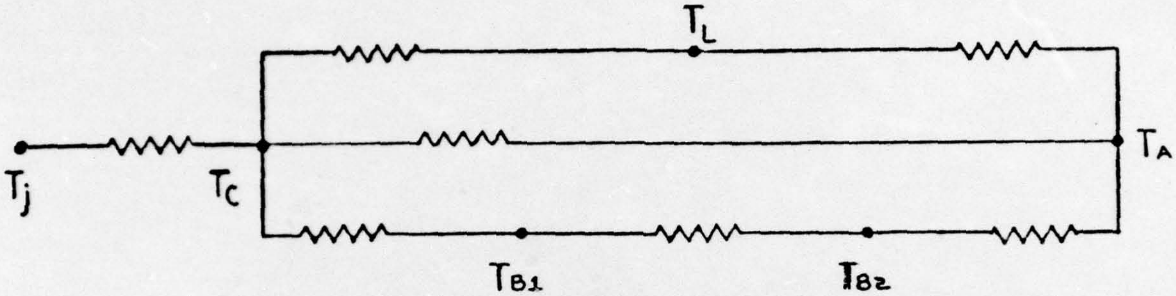
26. GENERAL MECHANICAL - An evaluation of the general mechanical design of the candidate module. This includes such considerations as key pins, pin shields, handling interfaces, marking surfaces, etc.

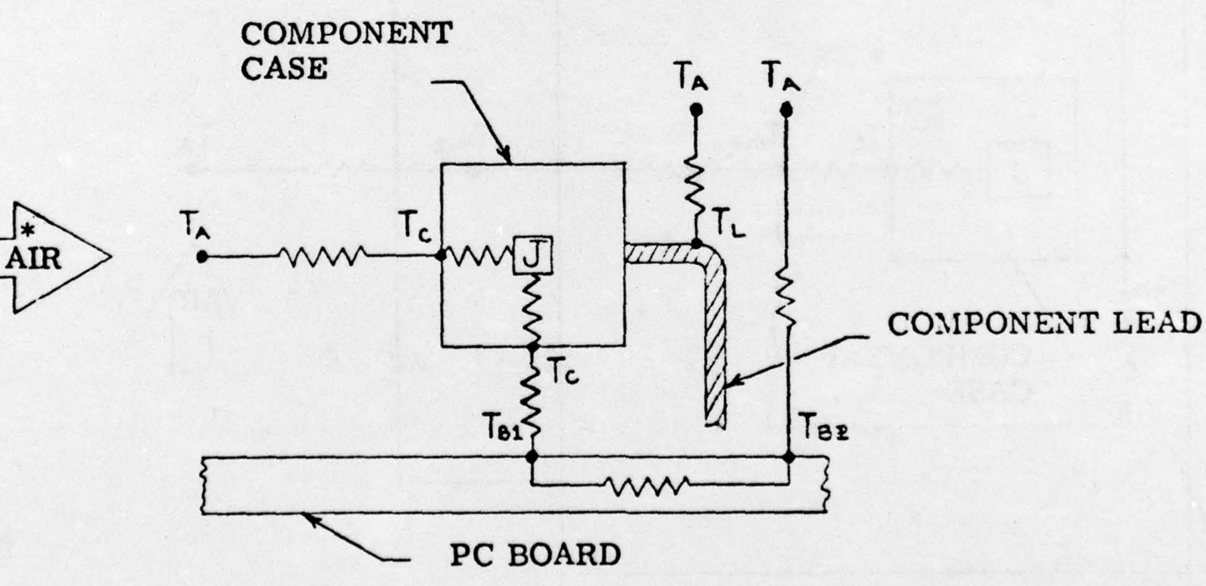
27. SYSTEM MAINTAINABILITY - The impact of module mechanical design of system maintenance (the impact for example of extraction or replacement method on MTTR).

APPENDIX E

SIMPLIFIED THERMAL MODELS

MODEL I

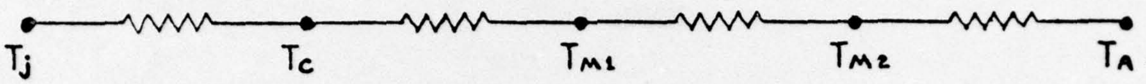


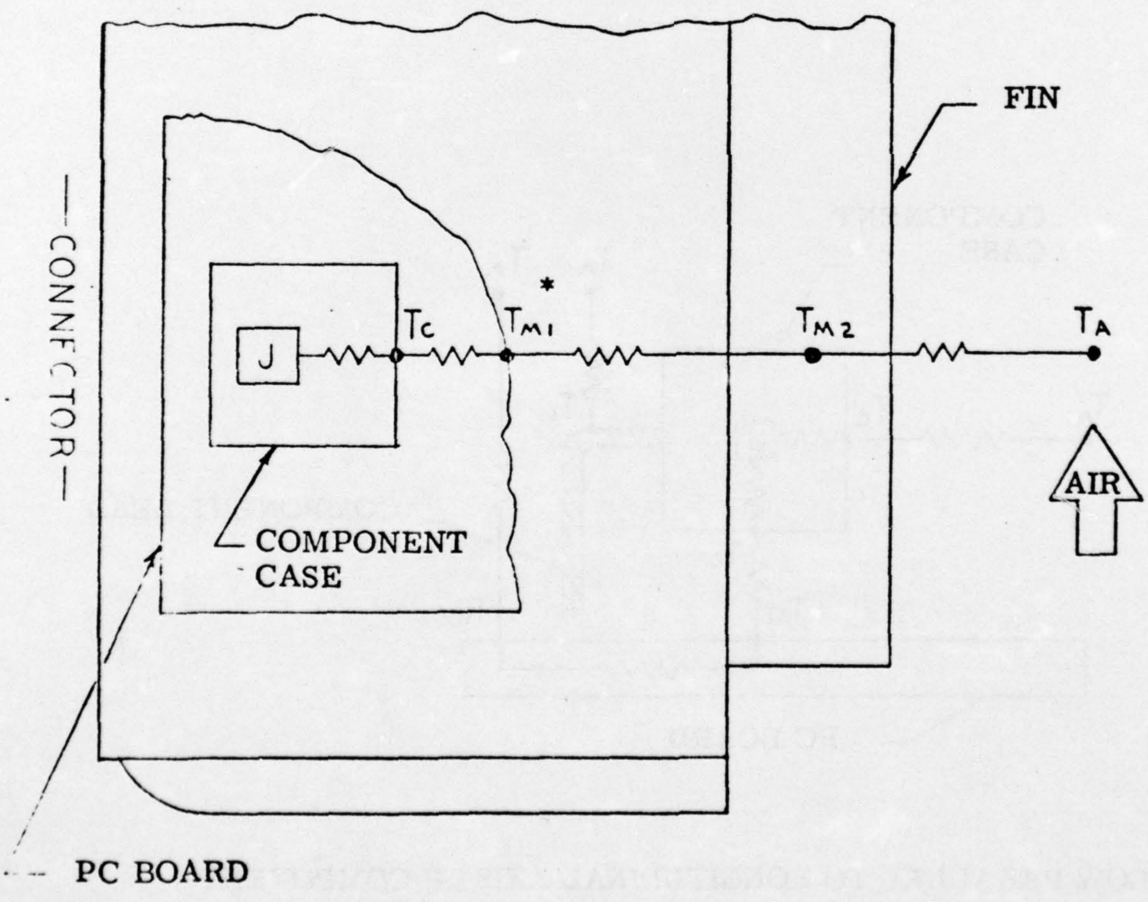


* AIRFLOW PARALLEL TO LONGITUDINAL AXIS OF COMPONENT

Figure 1. Direct Air Impingement

MODEL II

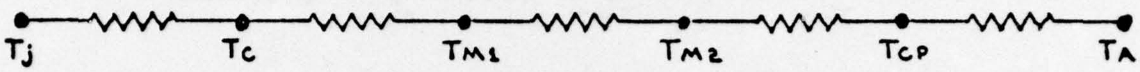


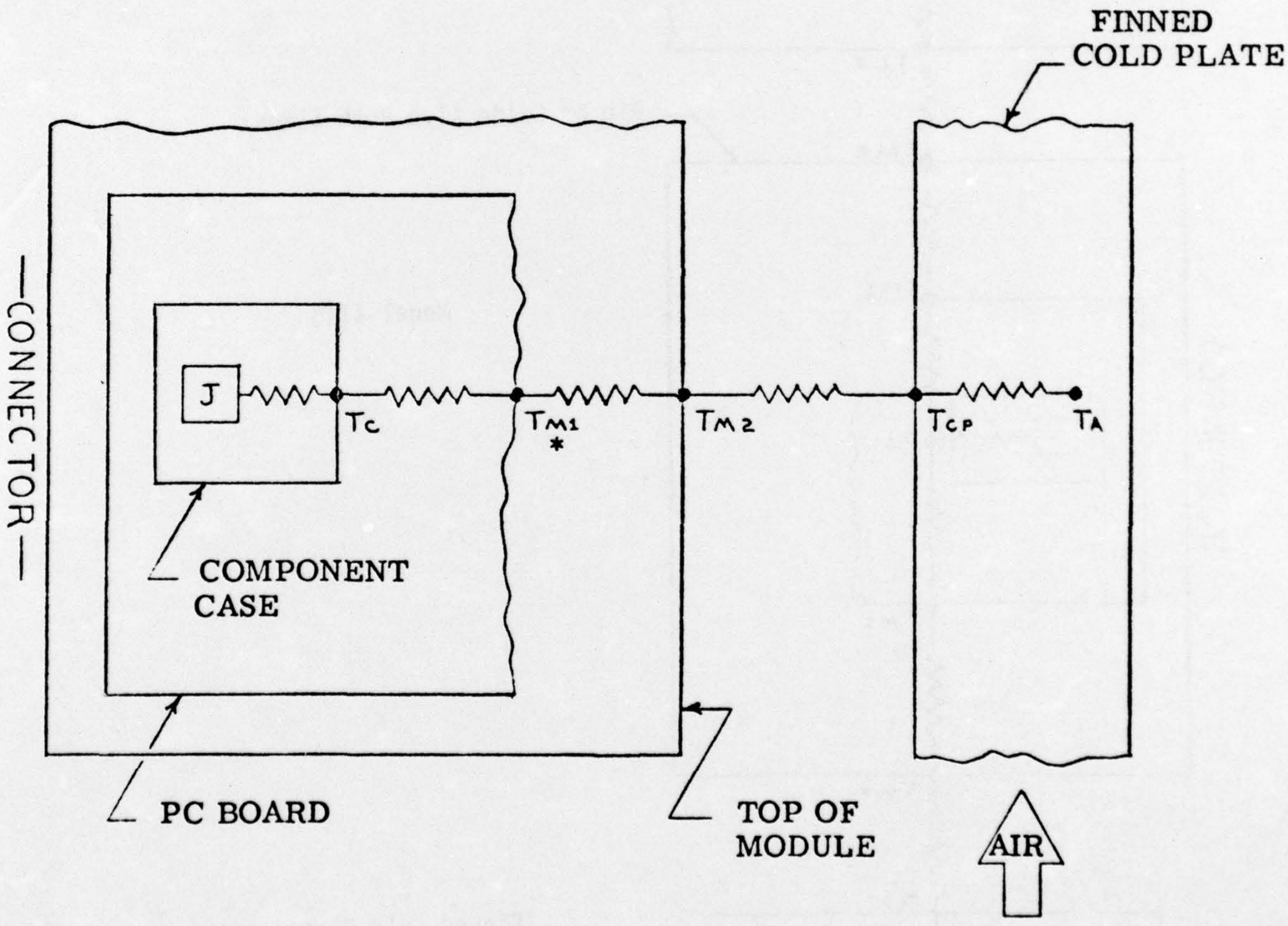


* T_{M1} IS SUBSTRATE TEMPERATURE DIRECTLY UNDER COMPONENT CASE

Figure 2. Conduction: Convection from Module Fin

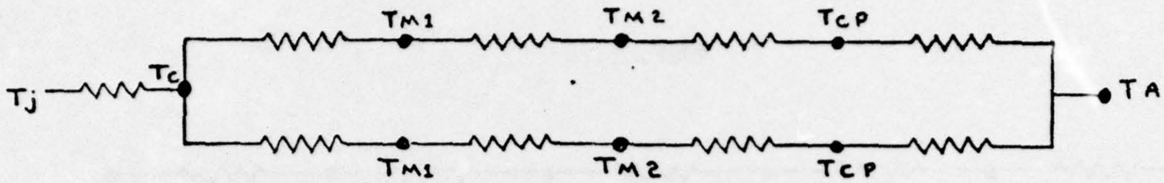
MODEL IIIA

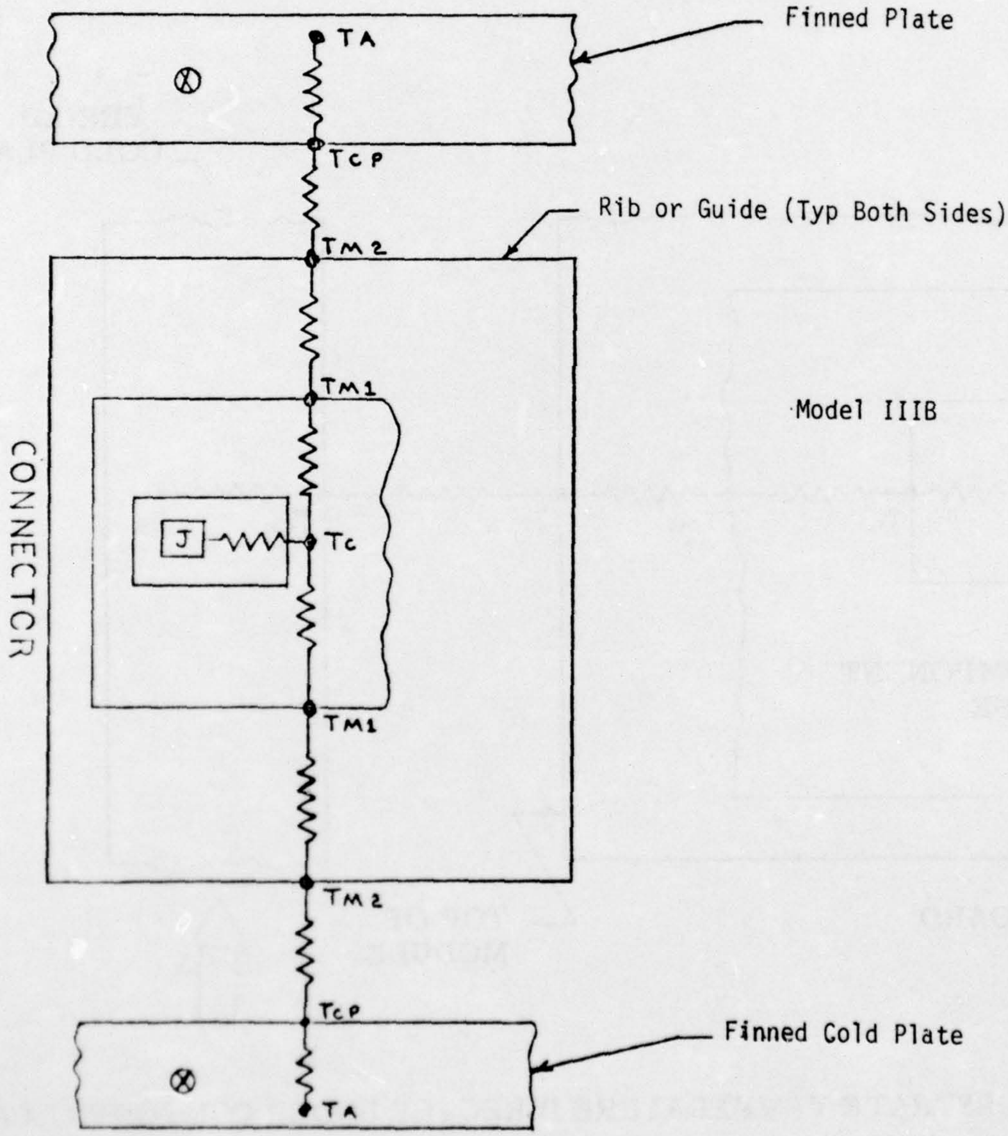




* T_{M1} IS SUBSTRATE TEMPERATURE DIRECTLY UNDER COMPONENT CASE

Figure 3. Conduction: Convection from Top Mounted Cold Plate





— ⊗ AIR OR WATER INTO COLD PLATE

— T_{M2} IS SUBSTRATE TEMPERATURE DIRECTLY UNDER COMPONENT CASE

Figure 4. Conduction: Convection from Side Mounted Cold Plates

Model IV

CONDUCTION: CONVECTION FROM HOLLOW CARD COLD PLATE INTEGRAL WITH MODULE

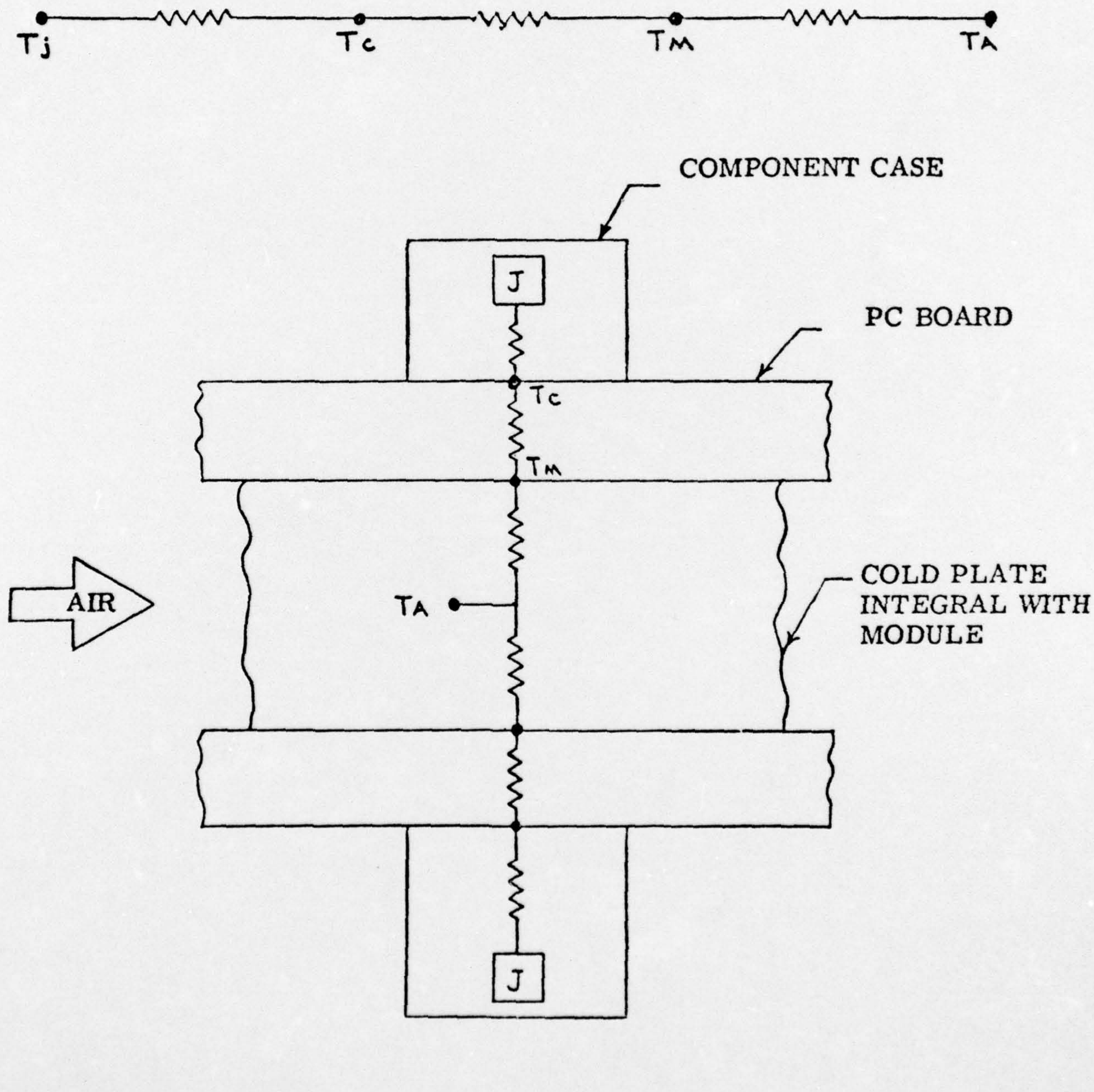


FIGURE 5

Figure 5. Conduction: Convection from Hollow Card Cold Plate Integral With Module

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SEM (Standard Electronic Module)

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report summarizes the SEM Exploratory Development module packaging studies accomplished by NAFI and NWSC, Crane during FY 1976. The primary outputs of these studies are the criteria and background data to be used in the definition of a SEM conceptual module, or family of modules, compatible with higher level electronic functions.

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by B. D. Tague 114p UNCLASSIFIED

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1. SEM (Standard Electronic Module)

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